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Evaluation of Sediment Contamination in Upper Los Alamos Canyon

Reaches LA-1, LA-2, and LA-3

Environmental Restoration Project
A Department of Energy Environmental Cleanup Program

Los Alamos
NATIONAL LABORATORY
Los Alamos, NM 87545

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EXECUTIVE SUMMARY

This interim report presents the results of investigations on contaminated sediments in upper Los Alamos Canyon and recommendations concerning potential additional assessments, sampling and analysis, and remedial actions. The objectives of this work include defining the nature and extent of contaminants within the sediments of upper Los Alamos Canyon, evaluating potential human health and ecological risk related to these contaminants, and evaluating the processes that redistribute these contaminants and the consequences of this redistribution. The risk assessments presented in this report are preliminary and are intended to identify whether there is a need for immediate action to mitigate risk or additional data collection. More comprehensive risk assessments will be presented in future reports on Los Alamos Canyon that will incorporate the results of ongoing groundwater investigations and additional sediment investigations.

Upper Los Alamos Canyon has received contaminants from multiple potential release sites (PRSs) within the watershed since the Laboratory was established in 1943. The most significant contaminant source was the 21-011(k) outfall at former Technical Area (TA) -21, where radioactive effluent was discharged between 1956 and 1985 into DP Canyon, a small tributary to Los Alamos Canyon. The second most important source for contaminants present in sediments along the stream channel was apparently an outfall that discharged onto Hillside 137 at former TA-1 between the mid 1940s and the mid 1950s. Additional sources exist at TA-1, TA-2, TA-21, and TA-53. Contaminants may also have reached the main channel from other technical areas and from residential and commercial areas in the Los Alamos townsite.

The technical approach followed in this investigation focused on detailed evaluations of contamination within three sections of upper Los Alamos Canyon, called "reaches." These reaches were selected (1) to encompass the range of potential risk related to contaminated sediments along the full length of the canyon downstream from the PRSs and (2) to allow testing and refinement of a conceptual model describing the distribution and transport of contaminants. Phased field investigations included detailed geomorphic mapping and characterization of post-1942 sediments, those sediments potentially containing contaminants resulting from Laboratory operations. An evaluation of data collected during each phase was used to revise the conceptual model, identify key uncertainties, and focus subsequent data collection.

The most significant chemical of potential concern (COPC) in the sediments of upper Los Alamos Canyon with regard to potential human health risk is cesium-137, which was released from TA-21 and is present downstream from DP Canyon. Plutonium-239,240, released primarily from former TA-1, is the most pervasive COPC upstream from DP Canyon. These radionuclides and other COPCs have been distributed by floods along the full length of upper Los Alamos Canyon downstream from former TA-1, a distance of more than 10 km, and have been dispersed laterally away from the stream channel for distances varying from less than 5 m to at least 25 m. Concentrations of cesium-137 in sediments transported by floods were highest during the early period of effluent releases from the 21-011(k) outfall, between 1956 and 1968, and concentrations dropped rapidly after 1968 following reductions in the discharge of cesium-137. Available data indicate that cesium-137 concentrations have been stable or have declined since 1978 and that concentrations will not increase in the future. Radionuclide concentrations are higher in relatively fine-grained sediment deposits of a given age than in associated coarse-grained sediment deposits; therefore, potential risk is higher in those areas where fine-grained sediments have been deposited. Because of these particle-size effects and time-dependent changes in contamination, cesium-137 concentrations are highest in fine-grained sediments that were deposited between 1956 and 1968. The highest concentrations of americium-241, cesium-137, plutonium-238,

strontium-90, and tritium were found close to DP Canyon, with much lower concentrations downstream near the Laboratory boundary. The highest concentrations of plutonium-239,240 have been found farther upstream, below former TA-1.

Inventories of the key radionuclides in upper Los Alamos Canyon sediments show geographic variations that are very similar to variations in radionuclide concentrations. Because risk is a function of contaminant concentrations, potential remedial actions that are designed to reduce either the total radionuclide inventory or the part of the radionuclide inventory most susceptible to remobilization in floods would therefore target the same areas as potential remedial actions designed to reduce risk at a site. Pockets of relatively fine-grained sediment that were deposited downstream from DP Canyon between 1956 and 1968 would be the primary target for remediation under either circumstance, and these areas could be easily identified using field measurements of gamma radiation.

Two of the most important radionuclide COPCs in upper Los Alamos Canyon, cesium-137 and strontium-90, have relatively short half-lives of 29 to 30 years, and significant decreases in concentration due to radioactive decay will occur over time frames relevant for evaluating risk and sediment remobilization. Implementing institutional controls that limit possible land uses until significant radioactive decay has occurred could therefore be an effective risk mitigation technique if measures to reduce risk are necessary.

Other COPCs identified in the sediments of upper Los Alamos Canyon include 9 radionuclides, 10 inorganic chemicals, and 23 organic chemicals. All these COPCs are found at low levels relative to the key radionuclides. In general, the concentrations of most of the other radionuclide and inorganic COPCs are positively correlated with either cesium-137 or plutonium-239,240 concentrations, indicating collocation of these COPCs and similar histories of release and transport. The concentrations of the organic COPCs are not correlated with the key radionuclides, and their sources and distributions are more poorly defined because of large gaps in data coverage. Collection of additional data on organic COPCs is needed to complete future human health and ecological risk assessments.

The preliminary assessments of potential human health and ecological risk presented in this report indicate that levels of contamination in the sediments of upper Los Alamos Canyon do not require immediate remedial actions with regard to present-day risk. In addition, because concentrations of contaminants in sediments carried by floods are not increasing over time and present levels of contamination have not been shown to either cause an unacceptable risk in downstream areas or exceed regulatory standards, no immediate remedial action is required in the context of future remobilization of contaminated sediments. Thus, possible decisions to implement any remedial action in upper Los Alamos Canyon should be made in the context of future assessments and/or future policy directives.

1.0 INTRODUCTION

1.1 Purpose

This interim report describes sediment investigations conducted in upper Los Alamos Canyon (Figure 1.1-1) in 1996, 1997, and 1998 by personnel from the Canyons Focus Area (formerly Field Unit 4) as part of the Los Alamos National Laboratory ("the Laboratory") Environmental Restoration (ER) Project. Investigations were focused on three reaches of the canyon following the technical strategy described in the *Task/Site Work Plan for Operable Unit 1049: Los Alamos Canyon and Pueblo Canyon* ("the work plan") (LANL 1995, 50290; LANL 1997, 56421) and modified by the *Core Document for Canyons Investigations* ("the core document") (LANL 1997, 55622; LANL 1998, 57666). Data collected from the three reaches in upper Los Alamos Canyon are used to define the nature and extent of contamination within young alluvial sediments (post-1942 sediments), to revise a conceptual model for contaminant distribution and transport, to perform preliminary assessments for potential human and ecological risk, and to determine if there is a need for immediate remedial action or additional data collection. In a future report these data will be combined with additional data on sediment, groundwater, and surface water in Los Alamos Canyon and Pueblo Canyon to support a canyons-wide assessment, which will involve a more comprehensive assessment of human and ecological risk related to present-day levels of contamination and the effects of future transport of contaminants.

1.2 Regulatory Context

Regulatory requirements governing the ER Project canyons investigations are discussed in Section 1.4 of the core document (LANL 1997, 55622). In particular these investigations address requirements of Module VIII of the Laboratory's Hazardous Waste Facility Permit ("the HSWA Module") (EPA 1990, 1585) under the Resource Conservation and Recovery Act (RCRA), including addressing "the existence of contamination and the potential for movement or transport to or within Canyon watersheds." In addition to federal and state regulations, Department of Energy (DOE) Order 5400.5, "Radiation Protection of the Public and the Environment," provides guidance on residual radioactivity at DOE facilities.

1.3 Background

1.3.1 Geography, Geology, and Hydrology

Los Alamos Canyon heads in the Sierra de los Valles on Santa Fe National Forest land below the north side of Pajarito Mountain and extends eastward across the Pajarito Plateau within the Laboratory boundary. Upper Los Alamos Canyon, as referred to in this report, is the area upstream from the confluence of Los Alamos Canyon and Pueblo Canyon. Upper Los Alamos Canyon has a drainage area of 27.8 km^2 and a basin length of approximately 20 km. Geologic units exposed within the upper Los Alamos Canyon watershed include Pliocene and Miocene dacites of the Tschicoma Formation, Quaternary ignimbrites of the Otowi and Tshirege Members of the Bandelier Tuff, and Quaternary pumice beds and volcaniclastic sediments of the Cerro Toledo interval (Griggs 1964, 8795; Smith et al. 1970, 9752). The part of the canyon within the Laboratory boundary is underlain by the Bandelier Tuff and the Cerro Toledo interval, except for the far eastern end where Pliocene basaltic rocks of the Cerros del Rio volcanic field are exposed.

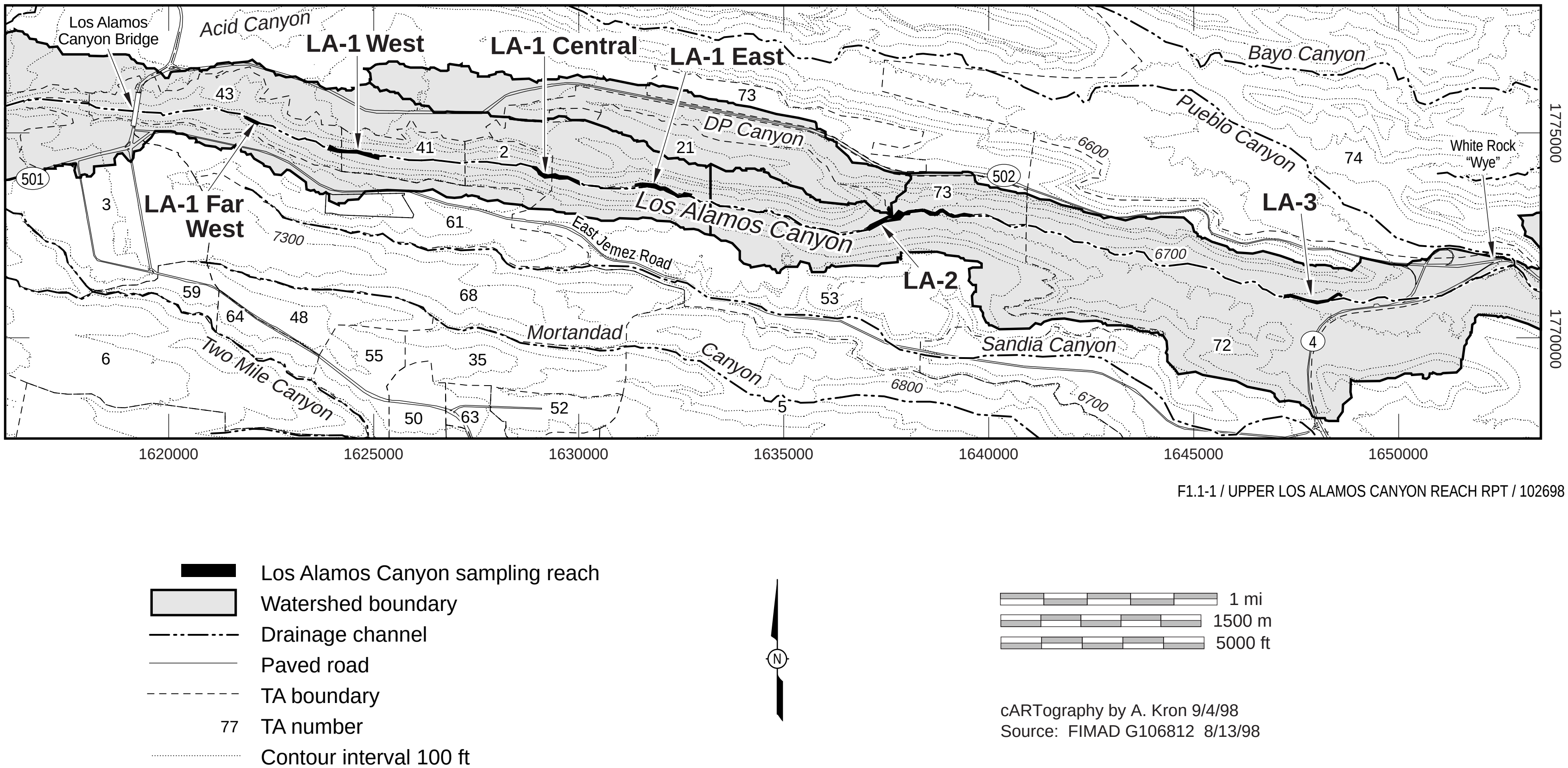

Figure 1.1-1. Map of the part of the upper Los Alamos Canyon watershed that includes Los Alamos National Laboratory, showing Laboratory technical areas and sampling reaches.

Stream flow in upper Los Alamos Canyon includes snowmelt runoff originating in the Sierra de los Valles and runoff from rain storms, which may often have local sources on the plateau. In some years snowmelt runoff extends completely across the plateau and crosses the eastern Laboratory boundary. In many years storm runoff also crosses the eastern Laboratory boundary and can reach the Rio Grande. DP Canyon is a source for many summer floods in upper Los Alamos Canyon, and the magnitude and frequency of these floods is enhanced by runoff from paved areas in the Los Alamos townsite at the head of DP Canyon.

1.3.2 Laboratory History and Operations

Several active and former Laboratory sites within the upper Los Alamos Canyon watershed have or may have contributed contaminants to the main channel of Los Alamos Canyon, including some of the original Manhattan Project laboratories within the current Los Alamos townsite that date back to 1943. Technical areas (TAs) that were or that might have been sources for contaminants include TA-1, TA-2, TA-3, TA-21, TA-41, TA-43, TA-53, and TA-61 (Figure 1.1-1). Brief summaries of pertinent information on key sites in the upper Los Alamos Canyon watershed are presented below.

1.3.2.1 Technical Area 1

Outfalls located in former TA-1 along the north rim of Los Alamos Canyon, within the current Los Alamos townsite, constitute significant sources of contamination for upper Los Alamos Canyon. TA-1 was established in 1943 during the Manhattan Project, and initial contaminant releases could date to this period. The contaminated areas are commonly referred to as Hillsides 137, 138, and 140 and are each the hillside component of a TA-1 aggregate of potential release sites (PRSs). Hillside 137 is within Aggregate G; Hillside 138 is within Aggregate F; and Hillside 140 is within Aggregate C (LANL 1992, 43454) (Figure 1.3-1).

Hillside 137 initially received direct discharges from a laundry for radioactively contaminated clothing, gloves, glassware, and other materials located in former Building D-2. The laundry was eventually moved to another building, and Septic Tank 137 (PRS 1-001[c]) was installed and connected by a drain line to an electronics shop in D-2. The buildings in Aggregate G were vacated in the mid 1950s (LANL 1992, 43454). Previous ER Project sample data for Hillside 137 indicated radionuclide concentrations above background values for plutonium-238; plutonium-239,240; uranium-234; uranium-235; and uranium-238. Inorganic chemicals reported as detected above background values include arsenic, barium, beryllium, chromium, lead, mercury, nickel, selenium, silver, thallium, and total uranium (LANL 1996, 54465).

Hillside 138 received discharges from Septic Tank 138 (PRS 1-001[d]). The septic tank was connected to former Buildings K, V, and Y, which were operational from the early 1940s through the late 1950s (Ahlquist et al. 1977, 5710; LANL 1995, 49703). Building K was used as a chemical stock room and contained a still for repurifying mercury (Mitchell 1944, 4984; Kershaw 1945, 4827). Uranium and beryllium machining and dry boron grinding was conducted in Building V (H-Division 1952, 32426). Building Y contained a cryogenics and physics laboratory that handled tritium, deuterium, uranium-238, and polonium-210 (Ahlquist et al. 1977, 5710). Previous ER Project sample data indicated radionuclide concentrations above background values for cesium-137; plutonium-238; plutonium-239,240; uranium-234; uranium-235; and uranium-238. Inorganic chemicals reported as detected above background values include arsenic, beryllium, chromium, lead, mercury, nickel, and silver (LANL 1995, 49703).

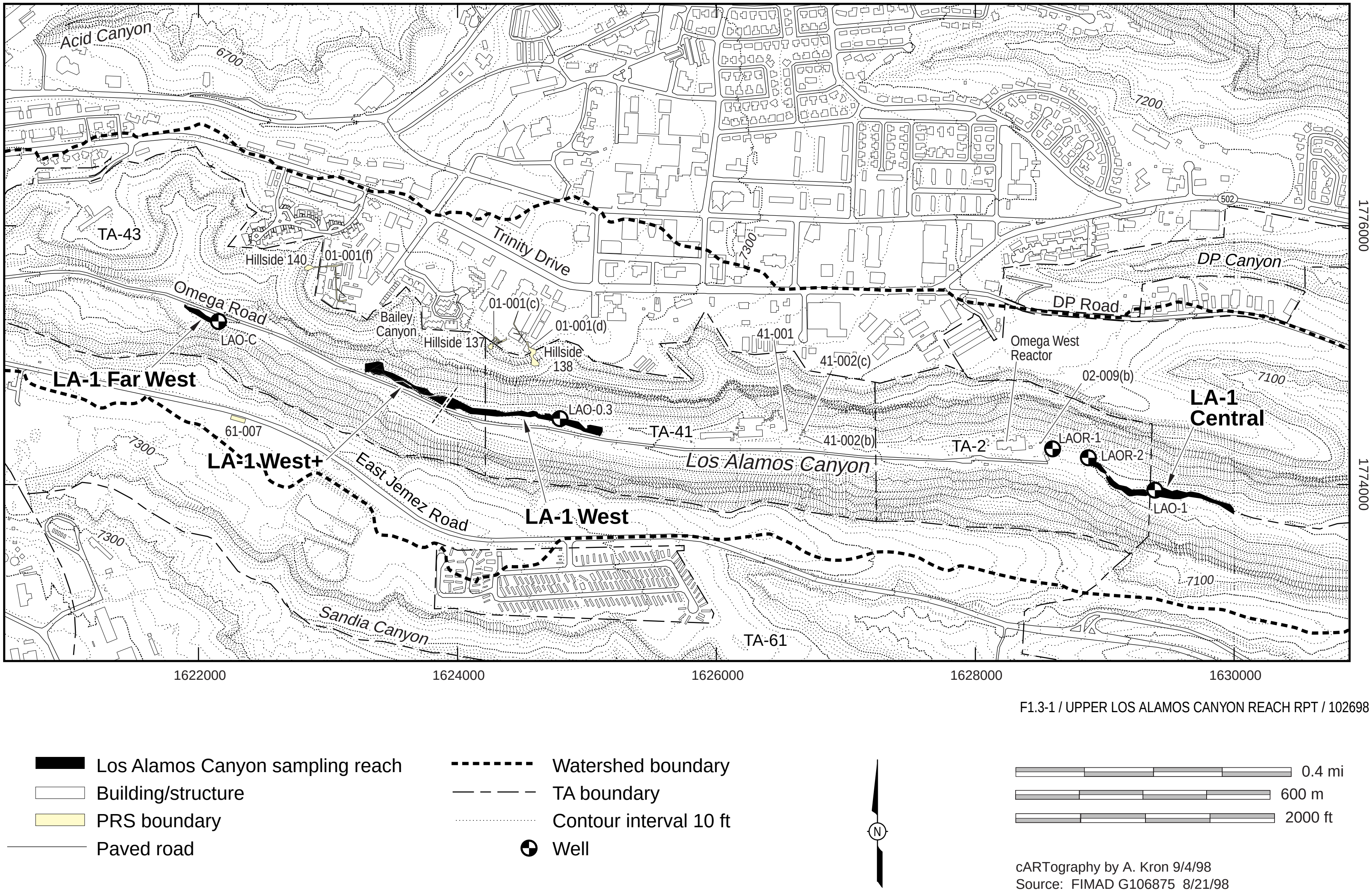

Figure 1.3-1. Map of upper Los Alamos Canyon showing reaches LA-1 West and LA-1 Central and the location of selected PRSs.

Hillside 140 received discharges from Septic Tank 140 (PRS 1-001[f]). The septic tank served the former HT Building, which was used for machining natural and enriched uranium for only six or seven months in 1945 (Ahlquist et al. 1997, 5710). Previous ER Project sample data indicate radionuclide concentrations above background values for plutonium-238; plutonium-239,240; uranium-234; uranium-235; and uranium-238. Inorganic chemicals detected above UTLs include antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and total uranium (LANL 1996, 54467).

1.3.2.2 Technical Area 2 and Technical Area 41

TA-2 and TA-41 are located within Los Alamos Canyon between reaches LA-1 West and LA-1 Central (Figure 1.3-1), and both sites have been used continuously since 1943 (LANL 1993, 21404). TA-2 has housed a series of research nuclear reactors, and TA-41 is used for weapons development and long-term studies of weapon subsystems.

Contaminants reported within soils and sediments at TA-2 include cesium-137; strontium-90; plutonium-239,240; chromium; mercury; silver; and uranium. The Omega West Reactor, which operated from 1956 to 1993, was a source of tritium releases into alluvial groundwater. Leach fields located east of Building 2-1 (PRS 02-009) were associated with water boiler reactors and have cesium-137 and strontium-90 above background values (LANL 1993, 21404).

The most important potential contaminant sources at TA-41 are a septic system (PRS 41-001) and a sewage treatment plant that operated from 1951 until 1987 (PRS 41-002). These PRSs may have plutonium, tritium, uranium, and perhaps other radionuclides above background values (LANL 1993, 21404).

Because ER Project investigations have not been completed at TA-2 and TA-41, the nature of contamination at these PRSs is only partially defined. In addition, results of both previous investigations and this investigation are inconclusive as to whether any of the TA-2 or TA-41 PRSs have been significant sources of contaminants for surface sediments along the active channel.

1.3.2.3 Technical Area 21

TA-21 was established in 1945 on DP Mesa and was the site of a plutonium processing plant and polonium and tritium research laboratories (LANL 1991, 7528). TA-21 includes the most significant source for contaminants in the upper Los Alamos Canyon watershed, outfall 21-011(k), which discharged northward into DP Canyon (Figure 1.3-2). Several other outfalls that discharged into DP Canyon or southward into Los Alamos Canyon may have also contributed contaminants to the main stream channels in these canyons. Information on the most significant PRSs that have been identified by ER Project investigations at TA-21 that may relate to contaminants in Los Alamos Canyon sediments are summarized below.

PRS 21-011(k), located on the north rim of DP Canyon, is an outfall that received radioactive liquid waste effluent from an industrial waste treatment plant located at Building 21-35 between 1956 and 1968, and effluent from a more recent industrial waste treatment plant between 1968 and 1985 (LANL 1991, 7529). This outfall has not been used since 1985. Radionuclides found above screening action levels (SALs) on the slope below the outfall include americium-241; cesium-137; plutonium-238; plutonium-239,240; and strontium-90. No other contaminants were identified above background values. Four hundred cubic yards of the most contaminated soil below the outfall were removed in an interim action in 1996, and the site is currently awaiting risk assessment for radioactivity before determining what future actions may be required (LANL 1995, 52350; LANL 1997, 55648).

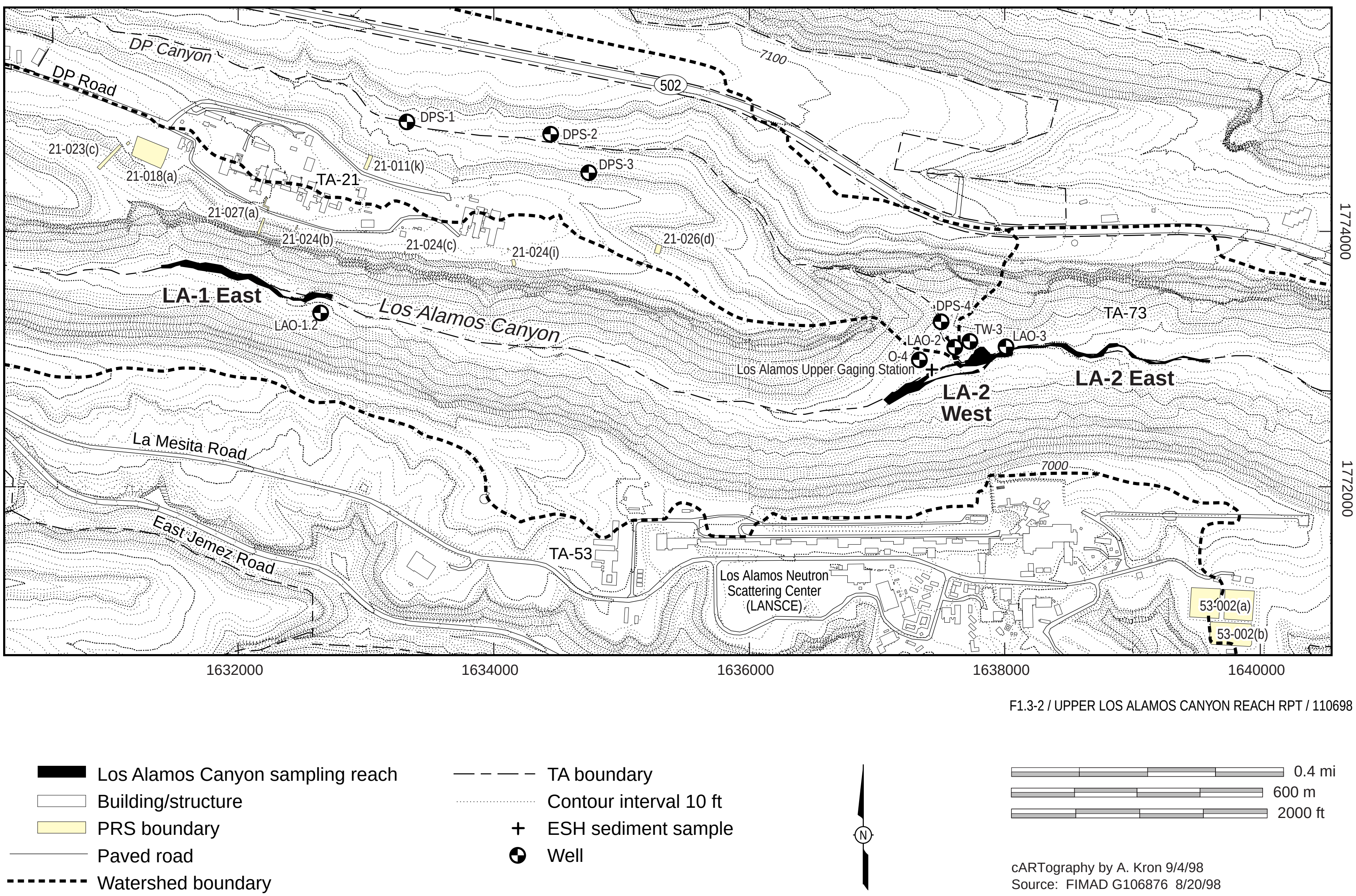

Figure 1.3-2. Map of upper Los Alamos Canyon showing reaches LA-1 East and LA-2 and the location of select PRSs.

PRS 21-018(a) consists of Material Disposal Area (MDA) V, which received liquid waste effluent from laundry operations in Building 21-20. MDA V includes three absorption beds on the south side of DP Mesa that sometimes overflowed into Los Alamos Canyon (LANL 1991, 7529). Sediment sampling in 1946 documented that plutonium from this source was entering the main stream channel in Los Alamos Canyon at that time (Kingsley 1947, 4186). Analytes identified above SALs include the metals antimony, cadmium, copper, lead, mercury, and uranium and the radionuclides americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; tritium; uranium-234; uranium-235; and uranium-238 (LANL 1996, 54969).

PRS 21-023(c) was a septic system that routed sewage from Building 21-33 through Septic Tank 21-62 to the south rim of DP Mesa (LANL 1991, 7529). Building 21-33 housed a waste treatment laboratory where research into the recovery of plutonium from liquid process wastes was performed. The septic system was installed in 1948 and removed in 1965. Radionuclides identified at concentrations above a local TA-21 baseline were americium-241; plutonium-238; plutonium-239,240; strontium-90; and uranium; americium-241 and plutonium-239 were detected above SALs. Metals identified above baseline concentrations but below SALs were arsenic, cadmium, chromium, copper, lead, nickel, and zinc (LANL 1995, 52350).

PRS 21-024(b) is a septic system that routed sewage from Building 21-17 through Septic Tank 21-55 to the south rim of DP Mesa. The outfall presently consists of a short cast iron pipe inside the security fence (LANL 1991, 7529). Analytes identified above the TA-21 baseline include the radionuclides americium-241; plutonium-239,240; tritium; and total uranium and the metals arsenic, chromium, nickel, selenium, and zinc. Only plutonium-239,240 concentrations were above SALs (LANL 1995, 52350).

PRS 21-024(c) is a septic system that routed sewage from Building 21-54 (removed in 1969) through Septic Tank 21-56 (abandoned in place in 1966) to the south rim of DP Mesa (LANL 1991, 7529). Analytes identified above the TA-21 baseline include the radionuclides americium-241; plutonium-239,240; strontium-90; tritium; and total uranium and the metals cadmium, chromium, copper, lead, nickel, silver, and vanadium. Chromium and lead exceeded SALs in the surface soil. Low concentrations of polychlorinated biphenyls (PCBs) and other unidentified organic chemicals were also detected (LANL 1995, 52350).

PRS 21-024(i) is a septic system that routed sewage from Building 21-152 through Septic Tank 21-181 (abandoned in place in 1965) to the south rim of DP Mesa (LANL 1991, 7529). Current ER Project investigations indicate the radionuclides actinium-227, tritium, and uranium isotopes and the metals arsenic, barium, chromium, copper, lead, mercury, selenium, vanadium, and zinc are present above background values. Arsenic, chromium, and lead were also detected in previous investigations with arsenic exceeding SALs. Low concentrations of PCBs and other unidentified organic chemicals have also been reported (LANL 1995, 52350).

PRS 21-026(d) is a National Pollutant Discharge Elimination System (NPDES) -permitted outfall from a sewage treatment plant on the eastern part of DP Mesa, which flows into a tributary drainage of DP Canyon (LANL 1991, 7529). Reconnaissance sampling in 1988 identified elevated levels of gross alpha, beta, and gamma activity and elevated tritium concentrations in the effluent. Subsequent ER Project investigations found concentrations of the radionuclides americium-241, tritium, and plutonium-239,240 and the inorganic chemicals cadmium, chromium, copper, nickel, silver, and zinc above the TA-21 baseline. Numerous semivolatile organic compounds (SVOCs) that are characteristic of paving materials were detected, including benz(a)anthracene, benzo(a)fluoranthene, and indeno[1,2,3-cd]pyrene at maximum concentrations at least four times their SALs. Chrysene was detected at a maximum concentration approximately 50% of its SAL (LANL 1994, 31591).

PRS 21-027(a) is a complex drainage system that routed liquid wastes from Building 21-3 to the south rim of DP Mesa. The system originates at the southwest corner of Building 21-3 with floor drains from equipment rooms, connects to a storm drain, and then empties into a ponding area. This area also receives NPDES-permitted discharges of treated cooling water effluent. The combined effluents from the pond flow eastward along the south side of the mesa to a culvert that carries them to the mesa edge (LANL 1991, 7529). The radionuclides americium-241; plutonium-238; plutonium-239,240; and total uranium have been found above background values with plutonium-238; plutonium-239,240; and americium-241 exceeding SALs. Arsenic was also detected above background value, and chromium was detected above SAL (LANL 1995, 52350).

1.3.2.4 Technical Area 53

TA-53 includes a proton accelerator and associated experimental and support buildings used for research with subatomic particles; it is the current site of the Los Alamos Neutron Science Center (LANL 1994, 34756). Construction began in 1967, and the accelerator became fully operational in 1974. Water from surface impoundments at the east end of TA-53, collectively known as PRSs 53-002(a and b), may have contributed contaminants to an unnamed tributary drainage to Los Alamos Canyon between reaches LA-2 and LA-3 (Figures 1.3-2 and 1.3-3). The surface impoundments received sanitary, radioactive, and industrial wastewater from various TA-53 buildings as well as septic tank sludge from other Laboratory buildings. The northern impoundments were active from the early 1970s until 1993. The southern impoundment came online in 1985 and is currently active and receiving radioactive liquid waste. The operating group tentatively plans to remove the southern impoundment in late 1998. Contaminants detected in impoundment sludge during previous investigations at 0.1 times SALs for noncarcinogenic chemicals or greater than SALs for radionuclides and carcinogenic organic chemicals include chromium, copper, lead, mercury, thallium, Aroclor-1254, Aroclor-1260, bis(2-ethylhexyl)phthalate, α-BHC, cobalt-60, neptunium-237, sodium-22, and tritium. Additionally, thallium, dieldrin, cesium-134, and manganese-54 were detected in the clay liner (LANL 1998, 58841).

1.3.2.5 Other Technical Areas

Laboratory sites at several other technical areas are located within the upper Los Alamos Canyon watershed and could potentially have contributed contaminants to the canyon floor, including TA-3, TA-43, and TA-61, although no PRSs in these technical areas have yet been identified as being actual contaminant sources for Los Alamos Canyon (LANL 1993, 51977). TA-3 is located south of the bridge across Los Alamos Canyon on Diamond Drive (Omega Bridge) and is a heavily developed technical area that includes the Laboratory administration building; only a small part of TA-3 drains into Los Alamos Canyon. TA-43 is a small technical area immediately north of the bridge that has housed the Health Research Laboratory since 1953 (LANL 1990, 7511). TA-61 is located along East Jemez Road near the Los Alamos County municipal landfill and has a few small support buildings. Significant PCB releases occurred at one TA-61 PRS (61-007) located within the topographic extent of the Los Alamos Canyon watershed (LANL 1993, 51977), although the PRS is immediately south of East Jemez Road; surface runoff from this mesa-top site may have been directed southward into Sandia Canyon instead of into Los Alamos Canyon. This site was remediated before the ER Project began.

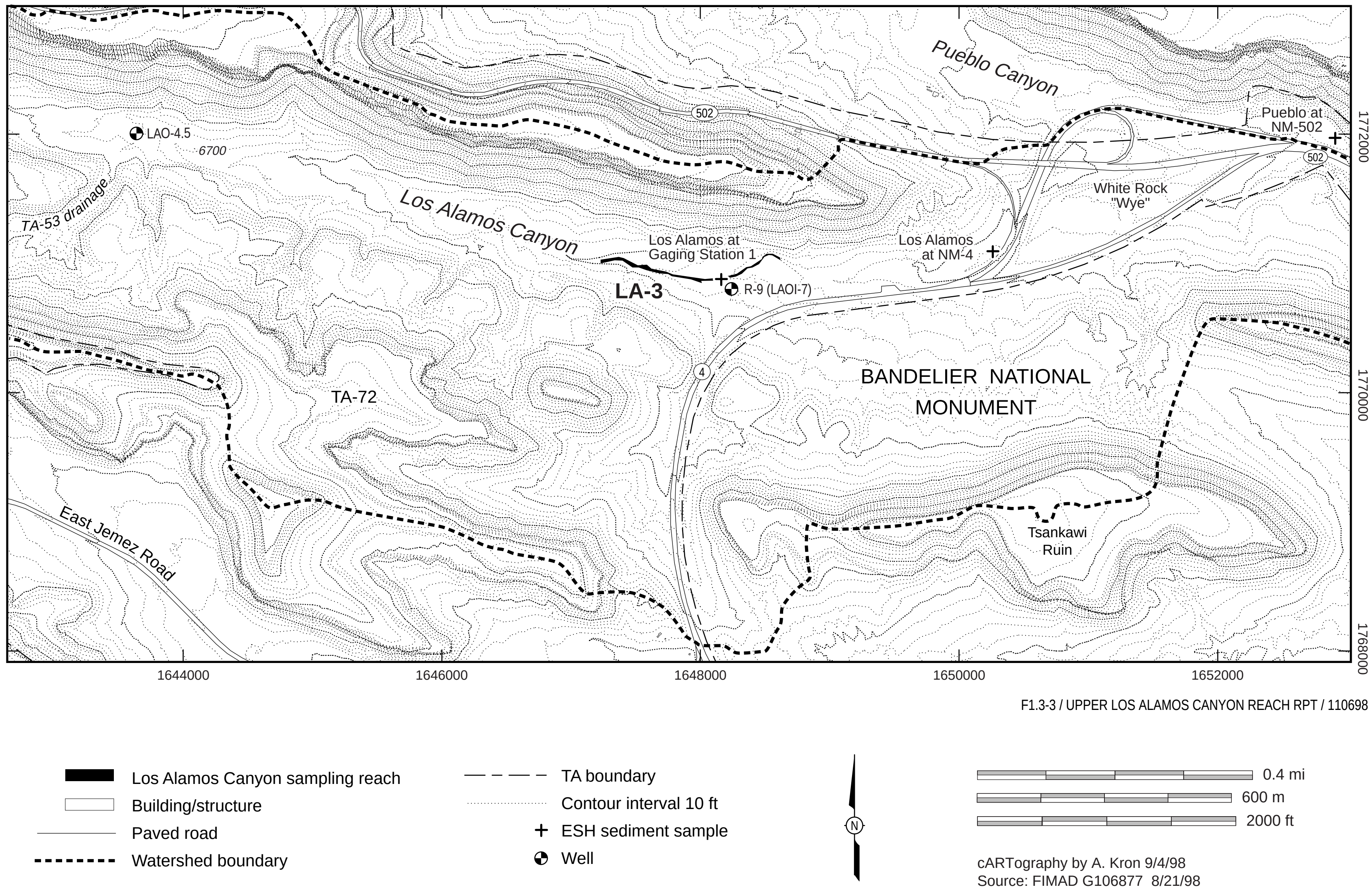

Figure 1.3-3. Map of upper Los Alamos Canyon including reach LA-3.

1.4 Current Land Use

Upper Los Alamos Canyon downstream from the bridge is entirely owned by DOE. Two Laboratory technical areas, TA-2 and TA-41, are located on the canyon floor, and these areas are closed to the public. TA-2 includes the Omega West nuclear reactor, which was closed in 1993 and is awaiting decontamination and decommissioning (D&D). TA-41 is an active technical area that has been used for weapons research. West of TA-41 is a paved road (Omega Road) that is open to the public. East of the TA-2 security fence is a dirt road that extends to state road NM 4; it is also open to the public. This part of the canyon is often used for recreational activities such as hiking (Kron 1993, 58665). The eastern part of upper Los Alamos Canyon near state road NM 4, including sampling reach LA-3 and extending downstream to the confluence with Pueblo Canyon (Figure 1.3-3), is presently being considered for potential land transfer to either Los Alamos County or San Ildefonso Pueblo (DOE 1998, 58671)**.**

1.5 Previous Sediment Investigations

Contaminants associated with sediments in upper Los Alamos Canyon have been investigated in many studies since the Laboratory was established in 1943. The first sediment sampling, in 1946, indicated the presence of plutonium at several sites within the canyon, with the highest concentrations reported below the outfall from the TA-21 laundry (PRS 21-018[a]) (Kingsley 1947, 4186). Subsequent work has included repeated sediment sampling at a series of stations as part of the Laboratory Environmental Surveillance Program since 1970 (e.g., Environmental Surveillance and Compliance Programs 1997, 56684) and more detailed topical studies. Additional studies that included sediment sampling have been conducted associated with the Laboratory Environmental Surveillance Program (e.g., Purtymun 1971, 4795; Purtymun et al. 1990, 6992); the Laboratory Environmental Sciences Group (e.g., Hakonson and Bostick 1975, 29678; Nyhan et al. 1976, 11747; Nyhan et al. 1982, 7164); the ER Project (LANL 1995, 52974); and the New Mexico Environment Department (Dale 1996, 58930). An additional study was recently conducted by Arizona State University, combining existing data on plutonium in sediments with geomorphic mapping of Los Alamos Canyon downstream from DP Canyon to provide an improved estimate of the inventory of plutonium in the canyon (Graf 1995, 48851; Graf 1996, 55537). Some of this earlier work is summarized in the work plan (LANL 1995, 50290) and formed the basis for a preliminary conceptual model of contaminant distribution and transport and for design of a technical approach for the present investigations, as summarized in the next section.

1.6 Preliminary Conceptual Model and Technical Approach

Available data on contaminants in upper Los Alamos Canyon sediments before this investigation indicated that cesium-137; plutonium-239,240; and other radionuclides discharged into DP Canyon from TA-21 were the primary contaminants of concern, although releases of inorganic and organic chemicals also occurred. Because of their geochemical characteristics, nearly all the cesium and plutonium was expected to be adsorbed onto sediment particles, and subsequent transport of these radionuclides would have been largely controlled by sediment transport processes. Strontium-90 released from TA-2 and TA-21 was recognized as a major contaminant in alluvial groundwater and was also expected to occur within the sediments, although strontium-90 is more soluble and transport processes would be different than for cesium and plutonium. Contaminants associated with sediments have been dispersed by floods from the original release sites downstream within upper Los Alamos Canyon and also into lower Los Alamos Canyon and the Rio Grande. Contaminant concentrations in post-1942 sediments vary greatly, related to factors such as the distance from the source, sediment particle size, and the age of the deposit. Radionuclide concentrations are expected to be generally higher in sediment deposits closer to the source and in finer-grained sediments than in downstream deposits or in coarser-grained sediments. In addition, radionuclide concentrations are expected to be highest in sediment deposits that are relatively close to the age of the peak contaminant releases and lower in younger sediments (LANL 1995, 50290). Available data indicated that the plutonium inventory in upper Los Alamos Canyon was much less than in Pueblo Canyon, associated with both lower plutonium concentrations and smaller sediment volumes (Graf 1996, 55537), and that less investigation would thus be required in upper Los Alamos Canyon downstream from DP Canyon than in Pueblo Canyon.

The technical approach adopted in this investigation includes detailed geomorphic mapping and sediment sampling in a series of reaches selected at key locations in the canyon, following the “representative reach” concept presented by Graf (1994, 55536). This work was focused on determining the nature and extent of contamination, evaluating risk, and testing components of the preliminary conceptual model in a phased approach. Geomorphic mapping and sediment sampling concentrated on identifying and characterizing post-1942 sediments, those sediments younger than the initial contaminant releases. An evaluation of data collected in each phase was used to revise the conceptual model, identify key uncertainties, and focus subsequent data collection. Investigation goals include evaluating present and future potential risk, evaluating sediment transport processes and future contaminant redistribution, and providing data necessary to make decisions about possible remedial action alternatives.

1.7 Deviations from the Work Plan

While conducting the sediment investigations in upper Los Alamos Canyon, the Canyons Focus Area technical team made some modifications to the proposed work described in Section 7.2 of the work plan (LANL 1995, 50290). These deviations are briefly discussed below.

During implementation of the work plan the technical team realized that several potential source areas for contaminants upstream from DP Canyon might be more significant than originally thought, and that the single reach planned for investigation would be insufficient to determine the relative importance of different PRSs as source areas. Therefore, geomorphic mapping and sediment sampling were conducted in several additional areas not specified in the work plan, which increased the total area of investigation. Reach LA-1 was redefined from the area originally specified downstream from TA-2 to include several additional subreaches, and the original reach LA-1 was designated as LA-1 Central. LA-1 East extends downstream from the outfall channel draining the former TA-21 laundry (PRS 21-018[a]) (Figure 1.3-2), a site which had been identified as having the highest levels of plutonium in either Los Alamos Canyon or Pueblo Canyon in 1946 (Kingsley 1947, 4186). LA-1 West extends downstream from the Hillside 137 drainage channel and includes the Hillside 138 drainage channel (Figure 1.3-1), both of which were below outfalls from the original Manhattan Project plutonium building and related buildings; ER investigations completed after the work plan was written identified both of these sites as potentially significant contaminant sources (LANL 1995, 49703; LANL 1996, 54465). LA-1 West+ extends upstream from the Hillside 137 drainage channel and is downstream from both Bailey Canyon (which receives drainage from several TA-1 PRSs) and Hillside 140 and was used to evaluate possible contaminant contributions from additional TA-1 PRSs. Finally, LA-1 Far West is located upstream from the Hillside 140 drainage channel and all other former TA-1 PRSs and was used to evaluate if contaminants were present from other upstream sources.

Radiological field surveys conducted in upper Los Alamos Canyon in 1996 revealed that the concentrations of radionuclide contaminants upstream from DP Canyon were too low to allow definition of the extent of contaminated sediments using field instruments. Therefore, no radiological surveys were conducted in reach LA-1 during the 1997 investigations, and sample site selection in LA-1 was based entirely on geomorphic criteria instead of relying on field radiological data as was proposed in the work plan. The 1996 surveys also indicated that alpha radiation was too low to distinguish from background and that beta radiation was correlated with gamma radiation downstream from DP Canyon and therefore provided no additional information on contaminant distribution. Thus, investigations downstream from DP Canyon in 1997 used only field measurements of gamma radiation.

Sample preparation deviated from that specified in the work plan by the decision to sieve each sample to remove all gravel and organic matter larger than 2 mm before analysis. The work plan had specified removal by hand of large stones and organic and other debris, but the technical team decided later that this process would not provide enough consistency in sample preparation.

1.8 Unit Conventions

This report uses primarily metric units of measure, although English units are used for contours on topographic maps, in reference to elevations derived from topographic maps, and for New Mexico State Plane coordinates as shown on some maps. English units are also used for radioactivity (curies [Ci] instead of becquerels [Bq]). Scales with both metric and English units of distance are shown on maps. Conversions from metric to English units are presented in Appendix A-2.0.

1.9 Report Organization

Section 2 of this report presents results of the field investigations of sediments in the upper Los Alamos Canyon reaches. Section 2.1 introduces each reach and its major geographic characteristics. Section 2.2 describes the methods of investigation in the reaches, including geomorphic mapping, physical characterization of young sediments, radiological field measurements, and sediment sampling activities. Section 2.3 presents results of these field investigations in each reach, including physical and radiological characteristics of the geomorphic units and key aspects of the post-1942 geomorphic history.

Section 3 of this report presents analytical results from sediment samples collected in the upper Los Alamos Canyon reaches. Section 3.1 is a data review that evaluates which radionuclides and organic and inorganic chemicals should be retained as chemicals of potential concern (COPCs). Section 3.2 evaluates each COPC in the context of likely sources within the upper Los Alamos Canyon watershed and possible collocation with other COPCs. Section 3.3 presents a detailed evaluation of radionuclide data from sediment samples collected in each reach, focused on cesium-137 and plutonium-239,240, which were selected as key contaminants in this investigation. Included in Section 3.3 are discussions of variations in radionuclide concentration among the different geomorphic units in each reach, the relations of radionuclide concentration to the age and particle size characteristics of the sediment deposits, the amount (inventory) of different radionuclides contained within the different units, and the potential for remobilization of contaminants contained within the different units.

Section 4 of this report presents a conceptual model describing contamination in the sediments of upper Los Alamos Canyon, which has been revised and refined from the preliminary conceptual model presented in the work plan based on the results of this investigation. Section 4.1 discusses the present nature and extent of contamination in upper Los Alamos Canyon sediments. Section 4.2 discusses controls on contaminant distribution, including the effects of particle size variations on radionuclide concentration and temporal and spatial trends in contaminant concentration. Section 4.3 discusses the fate and transport of contaminants in the sediments of upper Los Alamos Canyon, including processes that have redistributed contaminants since the initial releases and future remobilization and transport of these contaminants.

Section 5 of this report presents preliminary assessments of potential human and ecological risk related to contaminants contained within the sediments of upper Los Alamos Canyon. Section 5.1 presents the human health risk assessment. Section 5.2 presents the ecological screening assessment.

Section 6 of this report summarizes key conclusions of this investigation, highlights key remaining uncertainties, and provides recommendations concerning possible additional assessments, data collection, and/or remedial action.

Section 7 presents references cited in this report.

Appendix A presents a list of acronyms used in this report, metric to English conversions, and metric prefixes.

Appendix B presents supplemental information on the characterization of geomorphic units in the upper Los Alamos Canyon reaches. Appendix B-1.0 presents dendrochronological analyses (tree-ring dating). Appendix B-2.0 presents data on the thickness of post-1942 fine-grained overbank facies sediment in the different geomorphic units. Appendix B-3.0 presents data on particle size characteristics and organic matter content in the sediment samples. Appendix B-4.0 presents radiological field measurements and a discussion of instrument calibration and use. Appendix B-5.0 presents the chronology of sediment sampling events in the upper Los Alamos Canyon reaches and the primary goals of each sampling event.

Appendix C presents the results of quality assurance (QA) and quality control (QC) activities pertaining to the upper Los Alamos Canyon sediment samples. Appendix C-1.0 summarizes the QA/QC activities. Appendix C-2.0 addresses inorganic chemical analyses. Appendix C-3.0 addresses radiochemical analyses. Appendix C-4.0 addresses organic chemical analyses. Appendix C-5.0 presents data qualifiers for the samples.

Appendix D presents analytical suites and results of sediment analyses in this investigation. Appendix D-1.0 presents target analytes and detection limits. Appendix D-2.0 presents sample request numbers and analytical suites for each sample. Appendix D-3.0 presents summaries of analytical results. Appendix D-4.0 presents analytical results for COPCs.

Appendix E presents supplemental statistical analyses of the analytical results of this investigation. Appendix E-1.0 presents statistical evaluations of the inorganic chemical data. Appendix E-2.0 presents statistical evaluations of the radionuclide data. Appendix E-3.0 evaluates the possible collocation of COPCs. Appendix E-4.0 presents an analysis of radionuclide concentrations in field QA samples and resampled layers.

Appendix F-1.0 presents the ecological scoping checklist for the upper Los Alamos Canyon reaches.

1.10 Acknowledgments

The authors of this report had the following responsibilities. Reneau was responsible for documenting the field investigations and interpreting the analytical results in the context of the field setting and was also the principal investigator for sediment characterization during the field work. Ryti was responsible for data review, statistical analyses, and ecological screening and was also the lead for statistical analysis during all phases of the field investigation. Tardiff was responsible for the human health risk assessment included in this report. Linn was responsible for the data validation activities included in this report.

In addition to the authors of this report, numerous individuals contributed to this investigation.

Paul Drakos, Danny Katzman, Eric McDonald, and Brad Wilcox contributed to the geomorphic characterization activities. Wilcox contributed to development of the original technical strategy in the work plan and to initial phases of the field investigation. McDonald contributed to initial phases of the field investigations; helped develop field criteria for recognizing buried soils and the thickness of post-1942 sediment deposits; performed bulk density measurements; and was the lead for particle size analysis and development of a sediment background data set. Drakos and Katzman contributed to the second year of the field investigations, and Drakos was the lead for dendrochronological analyses.

Linnea Wahl lead the radiological field screening activities and provided summaries of these activities. Gross gamma radiation walkover surveys were performed by the Environmental Restoration Group (ERG) (Dave Hunter, Darrio Rocha, and John Taylor) and CHEMRAD (Mike Blair, Chuck Flynn, and Brett Lawrence), and fixed-point radiological measurements were performed by ERG and by ERM under the direction of Wahl. Florie Caporuscio lead initial planning for the radiological screening activities.

Johnnye Lewis was the lead for risk assessment during the field investigations. Ralph Perona contributed to risk assessment activities during both the field investigations and report preparation. Alison Dorries was the lead for initial development of the risk assessment approach in the work plan.

Jeff Blossom, Marcia Jones, and Matt Rice provided geographic information system (GIS) support. Jenny Harris was the lead for sediment sampling. Deba Daymon was the field team manager. Data management support was provided by Felicia Aguilar, Candi Chroninger, Chelsea Leeches, and Robert Trujillo. Ken Mullen provided environmental surveillance data. Maureen Oakes served as editor for this report; Christy Fläming was the graphic artist, and Pam Maestas was the compositor. Assistance in this investigation was also provided by the following individuals, including help with field work, data analysis, and report preparation: Larry Baker, Andy Crowder, Clint Daymon, Dave Frank, Rose Gallaway, John Hayes, Lorrie Houston, Andi Kron, Jared Lyman, Greg McDermott, Mary Mullen, Trung Nguyen, Marty Peifer, Bill Phillips, Stephanie Pratt, Carmella Romero, Celina Salazar, Jim Santo, Cathy Smith, Darrill Stafford, Jeff Walterscheid, and Ray Wright.

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2.0 FIELD INVESTIGATIONS

2.1 Introduction to Reaches

The initial locations of the upper Los Alamos Canyon reaches were selected to address a variety of goals, including identifying variations in contaminant concentration, contaminant inventory, and risk along the length of upper Los Alamos Canyon and improving the understanding of transport processes (LANL 1995, 50290). Each reach was intended to be long enough to capture local variations in contaminant concentrations related to variations in the age, thickness, and particle size of young (post-1942) sediment deposits but short enough that the effects of downstream dilution of contaminants were minimized. During field work, the geographic boundaries of the reaches were finalized, including the addition of subreaches to better define geographic variations in contamination and to better identify contaminant sources. The locations of the reaches within the upper Los Alamos Canyon watershed are shown in Figure 1.1-1; larger scale topographic maps showing the relation of the sampling reaches to key Laboratory sites are included in Figures 1.3-1 through 1.3-3. The general nomenclature for the geomorphic units used in this report is discussed in Section 2.2.1.1, and the specific units in each reach are discussed in Section 2.3. Geographic characteristics of these reaches are briefly summarized below.

Reach LA-1 is located downstream from the Los Alamos Canyon bridge and includes several subreaches that may have received contaminants from a series of potential releases sites (PRSs) in Technical Area (TA) -1, TA-2, TA-3, TA-21, TA-41, and TA-43. The canyon floor is relatively narrow through LA-1, and the stream is incised into the Tshirege Member and the Otowi Member of the Bandelier Tuff. LA-1 Far West is a short subreach upstream of Hillside 140. LA-1 West+ is a short subreach between Bailey Canyon and Hillside 137. LA-1 West is located between the drainage channel from Hillside 137 and TA-41 and includes the channel draining Hillside 138. LA-1 Far West, LA-1 West+, and LA-1 West are the wettest of the upper Los Alamos Canyon reaches, usually having surface water. LA-1 Central is located downstream from TA-2 and is drier than LA-1 West, often lacking surface water. LA-1 East is located downstream from the channel draining the former laundry at TA-21 and is also usually dry.

Reach LA-2 includes the confluence of DP Canyon and Los Alamos Canyon. LA-2 West is a relatively short subreach located upstream from the confluence, and LA-2 East is a relatively long subreach located downstream from the confluence. LA-2 East includes the part of Los Alamos Canyon where contamination derived from TA-21 and discharged into DP Canyon is expected to be highest. The canyon floor is relatively narrow in LA-2, and the stream is incised into the Otowi Member of the Bandelier Tuff. The stream gradient is slightly less in LA-2 than upstream in LA-1, and the channel is usually dry.

Reach LA-3 is located a short distance upstream from state road NM 4. The canyon is wider here than in LA-2, but the part of the canyon floor containing the active floodplain is narrower. The stream flows less frequently here than in LA-2. Alluvium locally pinches out on basalt in the stream bed immediately downstream of LA-3.

2.2 Methods of Investigation

2.2.1 Geomorphic Mapping

Field investigations in each reach began by preparing a preliminary geomorphic map that focused on identifying young (post-1942), potentially contaminated sediment deposits and subdividing these deposits into geomorphic units with different age, sedimentological characteristics, and/or radiological characteristics. These geomorphic units delineate the horizontal extent of contamination in each reach and also provide grouping of areas with similar physical and/or radiological characteristics. Where uncertainties existed in identifying the limits of potentially contaminated sediments, boundaries were drawn conservatively such that the area potentially impacted by post-1942 floods was overestimated rather than underestimated.

Mapping in each reach was at a scale of 1:200 and involved taping distances along the channel from known reference points and frequently measuring unit width. Aerial photographs were not useful in mapping any of the upper Los Alamos Canyon reaches because of the narrowness of the active canyon floor and the density of vegetation. Boundaries between geomorphic units were typically defined on the basis of topographic breaks, vegetation changes, and/or changes in surface sediments, although in some areas boundaries are more approximate. In reaches LA-2 East and LA-3 field radiological measurements were used to distinguish some geomorphic units on the basis of variations in gross gamma radiation.

Geomorphic mapping was iterative, and the maps were revised after each phase of investigation in each reach. For example, in LA-2 East field radiological measurements were used to define a relatively small area with elevated cesium concentrations, which was broken out as a separate geomorphic unit (unit c3). In addition, geodetic surveying of sample locations that followed each sampling event often led to map revisions so that the surveyed sample locations were within the appropriate geomorphic unit (for example, the surveyed location of a sample site on a stream bank could plot within the active channel as depicted on a preliminary geomorphic map because of small inaccuracies in unit boundaries). Refining of the conceptual model during the investigations also resulted in reexamination of previous map assignments and additional revisions to the maps.

2.2.1.1 Geomorphic Unit Nomenclature

The nomenclature used for geomorphic units is consistent among reaches and subreaches whenever possible, although complete consistency was not possible. The following general convention was used for naming units.

The designation "c" refers to post-1942 channel units, which are areas occupied by the main stream channel or experiencing significant deposition of coarse-grained channel sediments sometime in the post-1942 period; "c1 " is the presently active channel, "c2" is the youngest recognized abandoned channel unit in each reach, and "c3" includes older abandoned channel units. The designation "c2b" is used in LA-2 East to define part of the c2 unit where gross gamma radiation is relatively high. Available data did not allow each named unit to be the same age in every reach, and a direct correlation of units between reaches is not possible. For example, isotopic ratios in sediment samples from the c3 unit in LA-3 indicates that it contains sediment of similar age to the c2 unit in LA-2 East and is younger than the c3 unit in LA-2 East.

The designation "f" refers to floodplain areas that were or may have been inundated by overbank floodwaters since 1942 but that were not occupied by the main stream channel; "f1 " indicates areas that were probably inundated by floods during this period, as shown by geomorphic evidence and/or analytical data; "f2" indicates areas that were possibly subjected to minor inundation but where the evidence is generally inconclusive. If f2 surfaces were inundated, the thickness of post-1942 sediment would be small.

Other designations on the geomorphic maps delineate various areas that have not been directly impacted by post-1942 floods downstream of potential contaminant sources. Following standard geologic nomenclature, "Q" indicates deposits from the Quaternary period. "Qal" refers to active channel alluvium in tributary drainages. "Qc" refers to colluvium. "Qt" refers to pre-1943 stream terraces that have not been inundated by post-1942 floods. "Qf" refers to fans from tributary drainages.

2.2.2 Physical Characterization of Young Sediments

Physical characterization of the geomorphic units included measurements of the thickness of post-1942 sediments, general field descriptions of particle size, and laboratory particle size analysis for samples submitted for standard chemical and/or radiological analyses. Bulk density was also measured on a subset of sample intervals for use in calculating contaminant inventories; these measurements are presented along with density measurements for Pueblo Canyon reaches in Reneau et al. (1998, 59159). The determination of unit thicknesses used a variety of approaches, including identifying the depth that the bases of trees are buried by sediment; recognizing buried soil horizons; and searching for the presence of "exotic" material that indicates a post-1942 age (e.g., quartzite clasts imported from quarries closer to the Rio Grande, coal, or various man-made materials). Cesium and plutonium analyses were also used at some sites to directly determine the thickness (i.e., vertical extent) of contaminated sediment and provide supporting evidence for the inferred thickness of post-1942 sediment, although in some areas these radionuclides may extend into pre-1943 sediment because of vertical translocation. Selected trees were cored for dendrochronologic analysis (tree-ring dating) to help confirm the thickness of post-1942 sediment and to provide improved age estimates for specific sediment deposits (see Stokes and Smiley 1968, 57644, for a discussion of tree-ring dating methods). Additional details of the methods and results of the physical characterization of post-1942 sediment in the upper Los Alamos Canyon reaches are presented in Appendix B.

An important distinction within the post-1942 sediments involves general particle size variations because contaminant concentrations tend to be higher in finer-grained sediments of a given age. Field measurements focused on differentiating "overbank facies" and "channel facies" sediments, which are similar to the "top stratum" and "bottom stratum" of Brakenridge (1988, 57640). As used in this report, "overbank facies" refers to sediment generally transported as suspended load during floods, which are commonly deposited on floodplains from water that overtops stream banks, and "channel facies" refers to sediment generally transported as bed load and deposited along the main stream channel. Overbank facies sediment has typical median particle size of silt to fine sand, and channel facies sediment has typical median particle size of coarse or very coarse sand; medium sands could be assigned to either facies, depending on the stratigraphic context. These facies are not restricted to specific geomorphic units; overbank facies sediment typically forms upper layers on floodplains and abandoned channel units and can also be found as thin layers along active channels, and channel facies sediment can be deposited on floodplains during large floods and associated with channel aggradation. It should also be stressed that these distinctions are somewhat arbitrary, with gradations commonly occurring. Nevertheless, they form an important basis for differentiating sediment deposits of similar age that may have much different levels of contamination.

2.2.3 Radiological Field Measurements

The initial geomorphic mapping in reach LA-2 was followed by use of a series of field instruments to define differences in alpha, beta, and gamma radiation among the geomorphic units and to focus subsequent sampling. Gross gamma radiation walkover surveys were conducted first, providing excellent spatial coverage of variations in gamma radiation although the individual measurements have relatively low precision. The walkover surveys were followed by higher precision "fixed-point" alpha, beta, and gamma radiation measurements at selected field locations. A subset of the fixed-point locations was selected for *in situ* gamma spectroscopy measurements. Most of these field measurements were made during a pilot study phase of investigation when the utility of different field methods was being evaluated. During this pilot study phase, gross gamma radiation walkover surveys were also conducted in reaches LA-1 Central and LA-3, and a gross beta radiation walkover survey was conducted in LA-1 Central. Levels of gamma radiation, largely related to cesium-137, were found to be high enough downstream from DP Canyon that field gamma radiation measurements provided excellent definition of horizontal and vertical variations in cesium concentration. Therefore, investigations in LA-2 East and LA-3 relied heavily on the gross gamma radiation walkover survey data and fixed-point gamma radiation measurements. Beta radiation was also elevated above background values in LA-2 East, but the fixed-point measurements indicated that beta and gamma radiation were strongly correlated such that the beta radiation data provided no additional information on contaminant distribution (Figure B4-6). The fixed-point alpha radiation measurements and the *in situ* gamma spectroscopy measurements were not found to be helpful in the field investigation. Because of this, only the gross gamma radiation measurements in reaches LA-2 and LA-3 are discussed in the body of this report, although methods and results for all the field instruments are presented in Appendix B-4.0.

2.2.4 Sediment Sampling and Preliminary Data Evaluation

Sediment sampling in this investigation followed a phased approach that included a combination of sampling for "full-suite," "limited-suite," and "key contaminant" analyses. Preliminary evaluation of data after each sampling phase was performed to help identify uncertainties and to focus subsequent sample collection and analysis. The primary goals and other information about each sampling event are summarized in Appendix B-5.0.

Full-suite analyses were obtained on samples from LA-2 and LA-3 after the field radiological surveys, with the goal of identifying all analytes that were present above background values and determining the primary risk drivers. The specific sample sites and sample depths included intervals with the highest field radiological measurements in each reach as well as intervals with relatively low radiation. The sample sites also included representative fine-grained and coarse-grained sediment deposits from the range of geomorphic units. The full-suite analyses included a series of inorganic chemicals, organic chemicals, and radionuclides and are listed in Section 3.1 and Appendix C.

Subsequent sampling phases in all reaches were primarily focused on key contaminants that were used to define the horizontal and vertical variations in contaminant levels. Cesium-137 was selected as a key contaminant for LA-2 East and LA-3 because preliminary risk assessments using the full-suite analyses indicated that cesium-137 is the main risk driver downstream from DP Canyon. Plutonium-239,240 (unresolved isotopes) was selected as a key contaminant in LA-1 and LA-2 West because it is the only analyte that is consistently present above background values in sediment samples upstream from DP Canyon. Specific sample sites in each sampling event were selected to reduce uncertainties in the horizontal and vertical extent of contamination, the average and range of contaminant concentrations in each unit, the inventory of the key contaminants, and controls on their distribution (e.g., effects of sediment age and sediment particle size).

To most effectively reduce the uncertainty in total plutonium inventory in each reach, a stratified random sample allocation process was applied (using calculations based on equation 5.10 in Gilbert 1987, 56179). To evaluate uncertainty in this sample allocation process, Monte Carlo calculations were performed using the Crystal Ball version 4 add-in to Microsoft Excel software. These calculations used available data on the area, thickness, and radionuclide concentration in each geomorphic unit and sediment facies to help determine the number of samples to be collected from each unit and each facies. For example, a unit with a relatively large volume of post-1942 sediment, high radionuclide concentrations, and/or high variability in radionuclide concentration would be assigned more samples than a similar unit with small volume, low concentrations, and/or low variability in radionuclide concentration.

In all reaches a series of samples were also collected for limited-suite analyses, including analytes measured above background values in the full-suite analyses in LA-2. The limited suite included metals, polychlorinated biphenyls (PCBs) and pesticides, and select radionuclides and is discussed in Section 3.0.

A primary goal of these limited-suite analyses was to evaluate to what degree concentrations of cesium and plutonium were correlated with concentrations of the other analytes and hence to what degree they are collocated within the same sediment deposits. Analytical results from the first sampling phases in LA-2 East indicated that the ratios of some of the radionuclides had varied over time (e.g., ratio of plutonium-239,240 to plutonium-238), and some of the limited-suite sampling was used to evaluate differences in sediment age. Sample collection for limited-suite analyses included sample intervals that had yielded the highest cesium or plutonium concentration within each reach as well as intervals with more representative concentration and including the range of geomorphic units and sediment facies that had been identified.

2.3 Results

2.3.1 Reach LA-1

2.3.1.1 Physical Characteristics

Reach LA-1 is in a part of upper Los Alamos Canyon with a narrow canyon floor. The area that has been impacted by post-1942 floods averages approximately 13 to 15 m wide in LA-1 West, LA-1 Central, and LA-1 East. The areal distribution of the geomorphic units is shown on Figures 1.3-1 and 1.3-2 and Figures 2.3-1 to 2.3-4, and topographic relations are illustrated in the cross sections of Figures 2.3-5 to 2.3-7. Physical characteristics of the geomorphic units in LA-1 are summarized in Table 2.3-1. Data on particle size and unit thickness are presented in Tables B3-1 and Table B3-4 and Figures B2-1 to B2-3.

The active channel, c1, averages 1.5 to 2 m wide in the different LA-1 subreaches and has a bed composed of coarse sand and gravel. The active channel is usually bordered by abandoned post-1942 channel units (c2, c3) that average approximately 4 to 5 m in combined width and have average heights of 0.4 to 1.0 m above the channel. The c2 and c3 units are usually capped by an average of approximately 0.2 to 0.4 m of relatively fine-grained overbank sediments dominated by fine to very fine sand. In parts of LA-1 Central and LA-1 East, the upper parts of the c3 units are composed of gravel and coarse sand that represent gravel bars deposited on older floodplains. In each subreach unit c3 has surfaces that are higher above the channel than c2, although the c2 and c3 units may have ages that overlap within and between subreaches.

Active floodplains (f1) in LA-1 are typically 4 to 5 m wide in LA-1 Far West and LA-1 West+ and broaden to an average width of 7 to 8 m in LA-1 West, LA-1 Central, and LA-1 East. The f1 unit averages 0.9 to 1.1 m above the active channel and is capped by an average of 0.1 to 0.25 m of overbank sediments dominated by very fine sand and coarse silt. Potentially active floodplains (f2) in the different subreaches are slightly higher than f1 and average from 0 to 4 m wide. These areas either have not been inundated by post-1942 floods or were only briefly inundated, experiencing little post-1942 sediment deposition.

2.3.1.2 Radiological Characteristics

Gross beta and gross gamma radiation walkover surveys in reach LA-1 Central in 1996 indicated that levels of beta- and gamma-emitting radionuclides were not high enough to allow contaminated areas to be distinguished from background radiation in LA-1. This conclusion was supported by field radiological data from reach LA-2 West and by analytical data on sediment samples collected from TA-2 and TA-41 (in former Operable Unit 1098). Therefore, field radiation measurements were not used in the geomorphic mapping in LA-1 in 1997 or to help select sample sites. A summary of the field radiation measurements in LA-1 Central and maps showing measurement locations are presented in Appendix B-4.0.

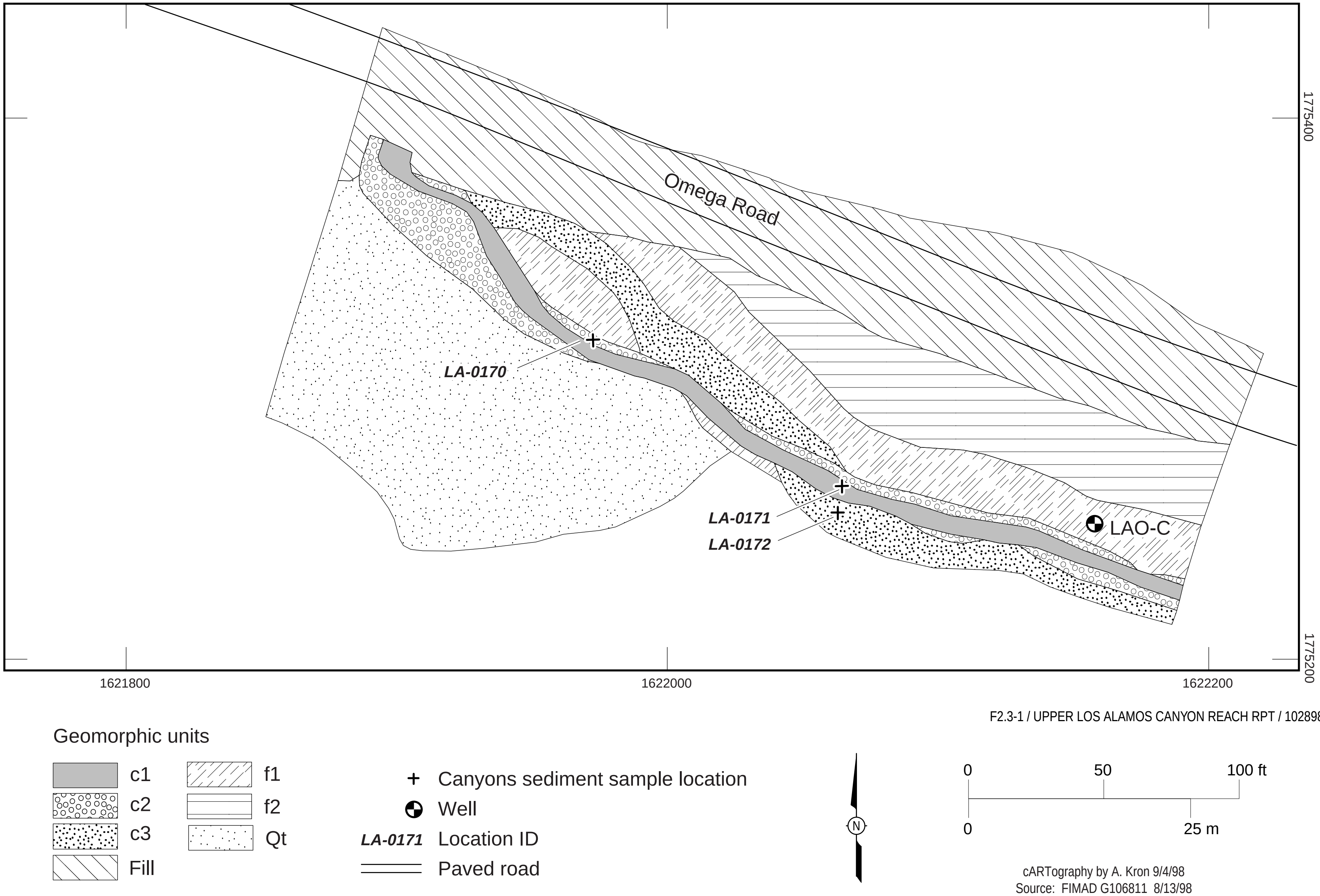

Figure 2.3-1. Geomorphic map of reach LA-1 Far West showing sample locations.

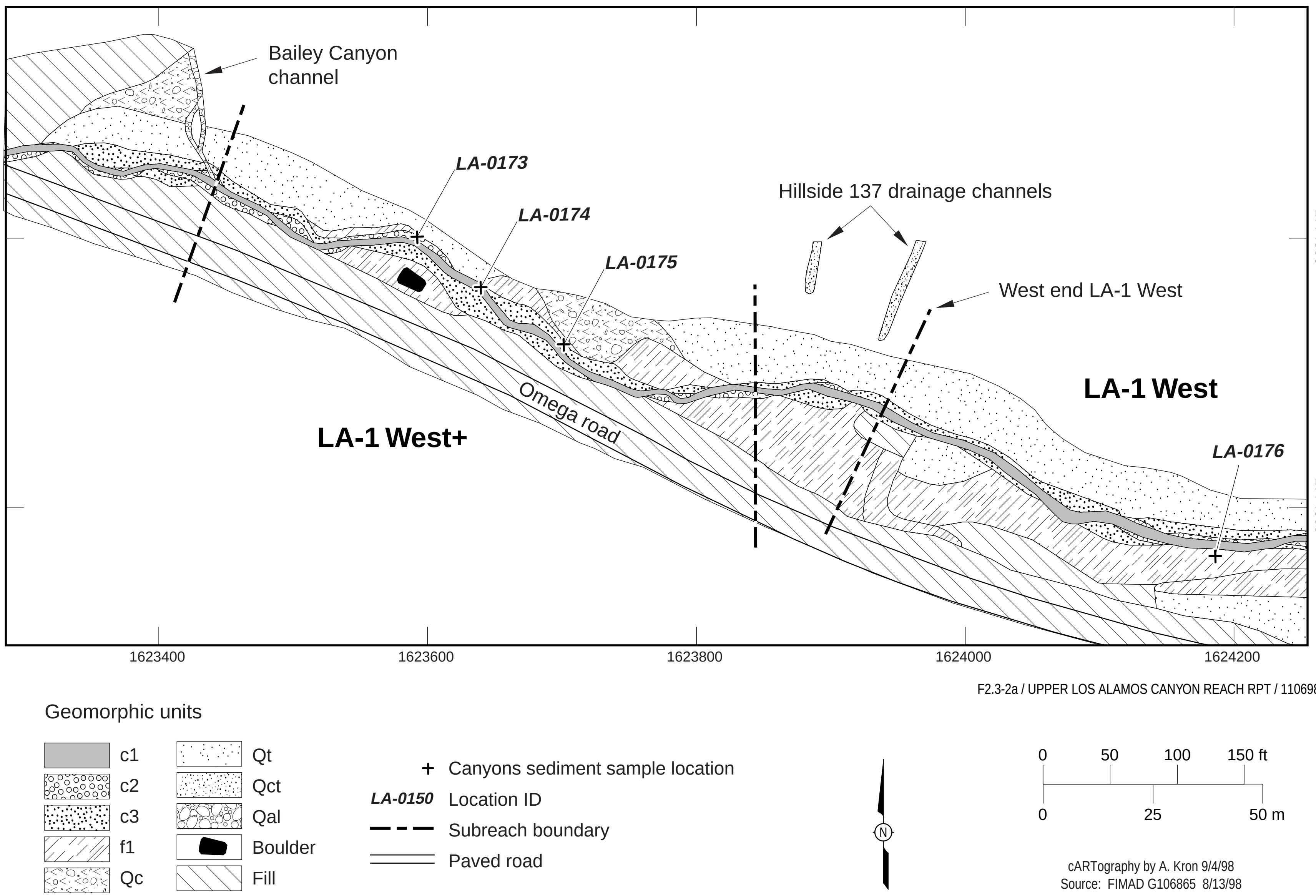

Figure 2.3-2a. Geomorphic map of reach LA-1 West+ showing sample locations.

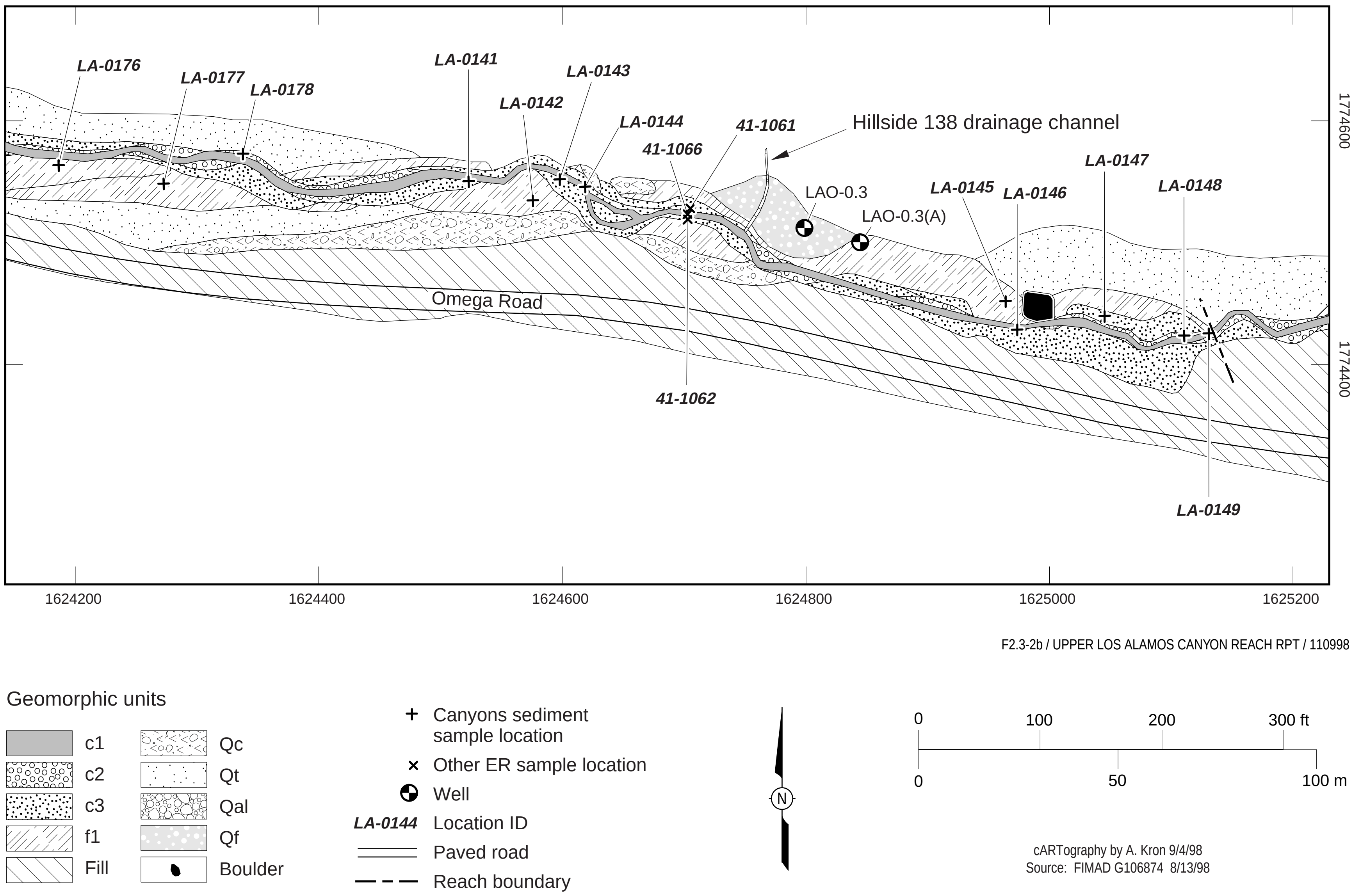

Figure 2.3-2b. Geomorphic map of reach LA-1 West showing sample locations.

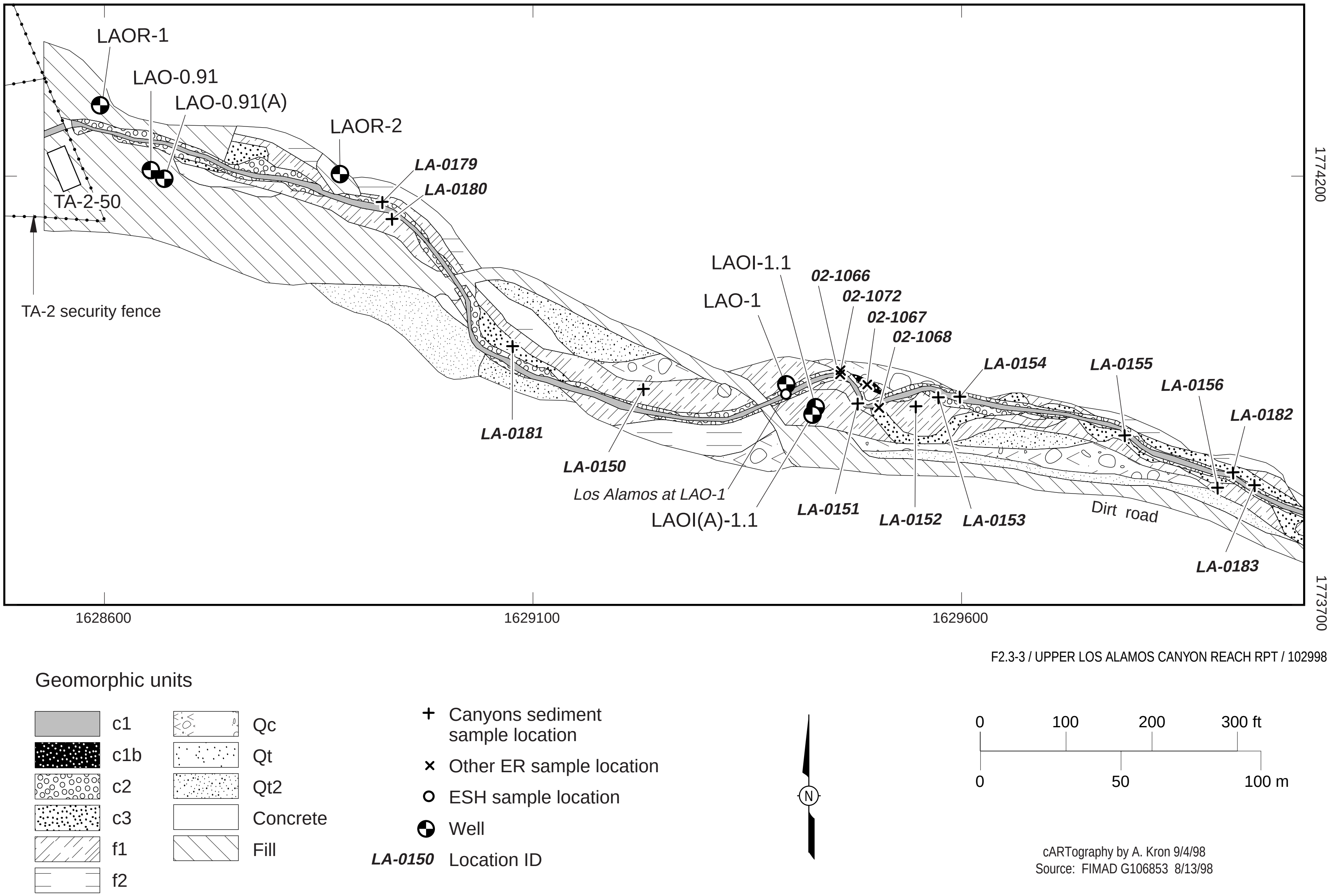

Figure 2.3-3. Geomorphic map of reach LA-1 Central showing sample locations.

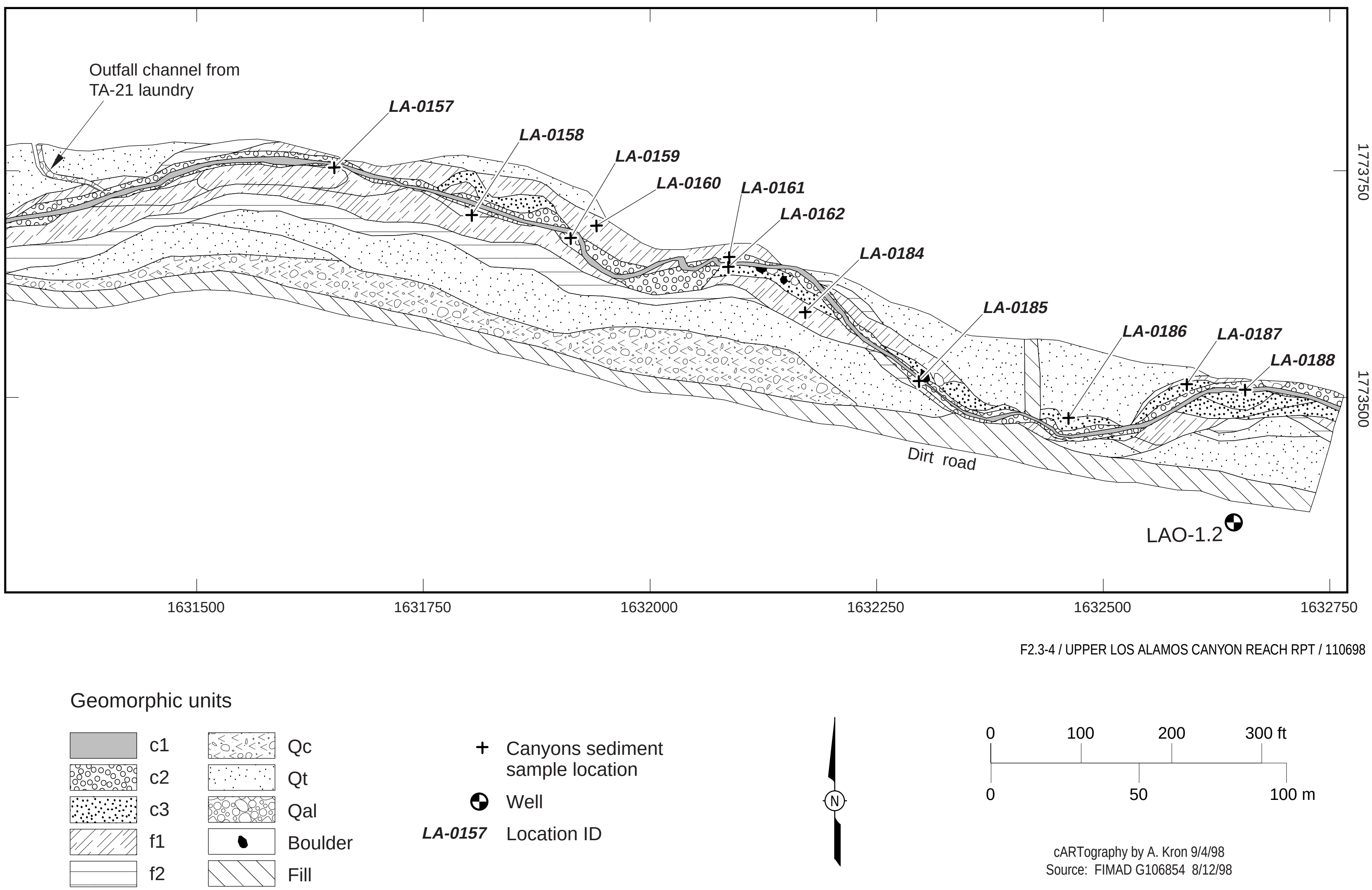

Figure 2.3-4. Geomorphic map of reach LA-1 East showing sample locations.

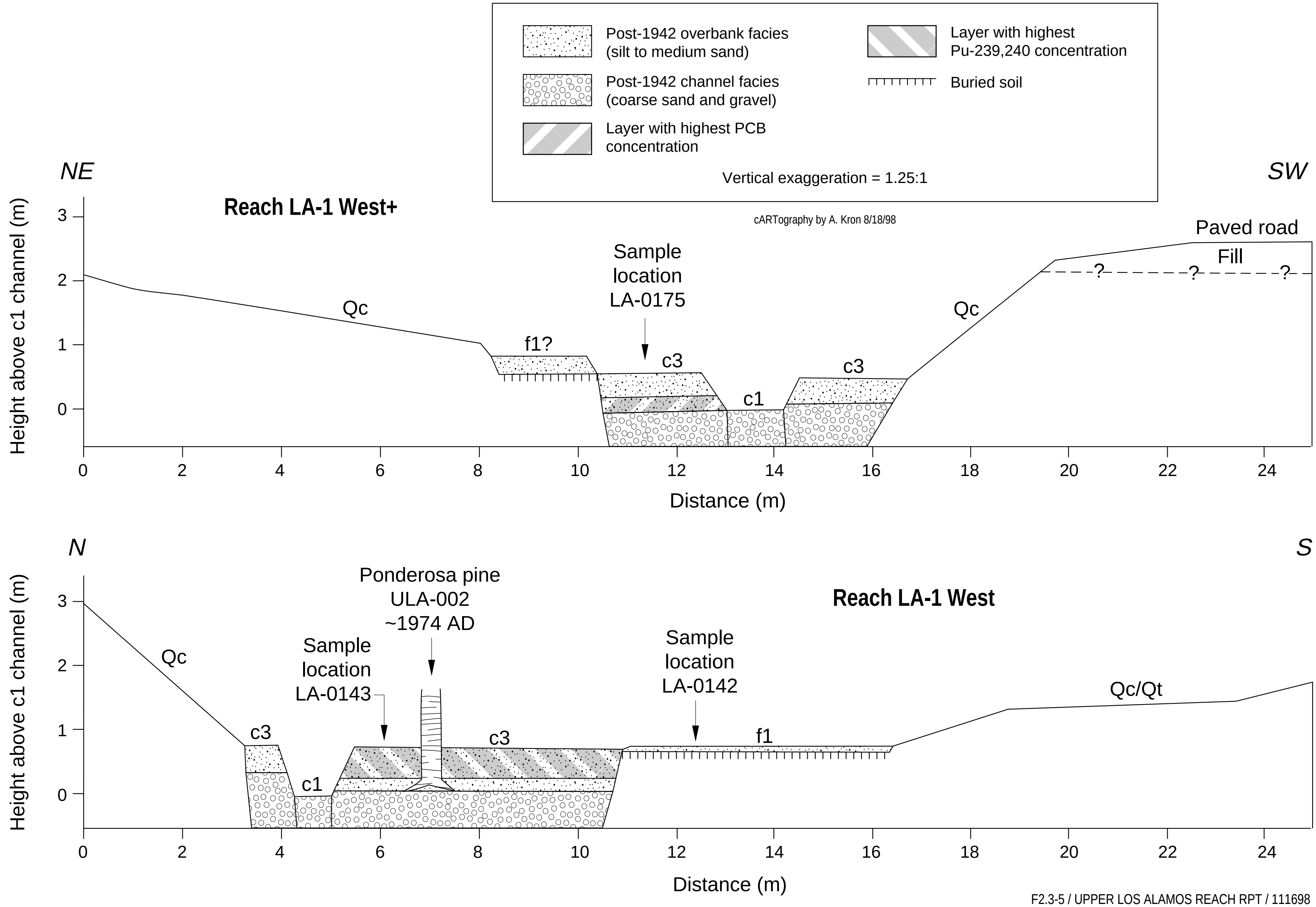

Figure 2.3-5. Schematic cross sections showing relationship between geomorphic units in reaches LA-1 West+ and LA-1 West.

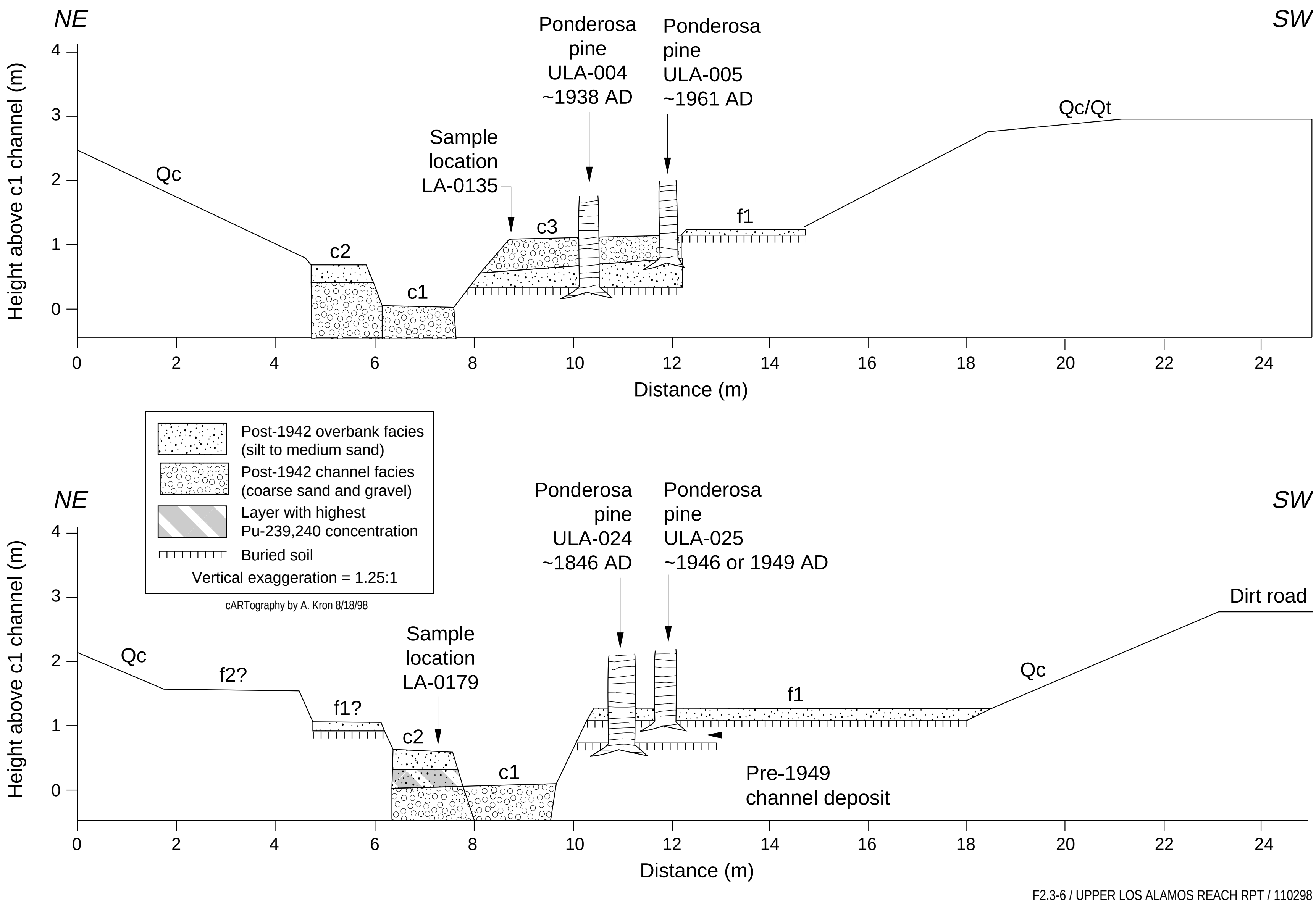

Figure 2.3-6. Schematic cross sections showing relationship between geomorphic units in reach LA-1 Central.

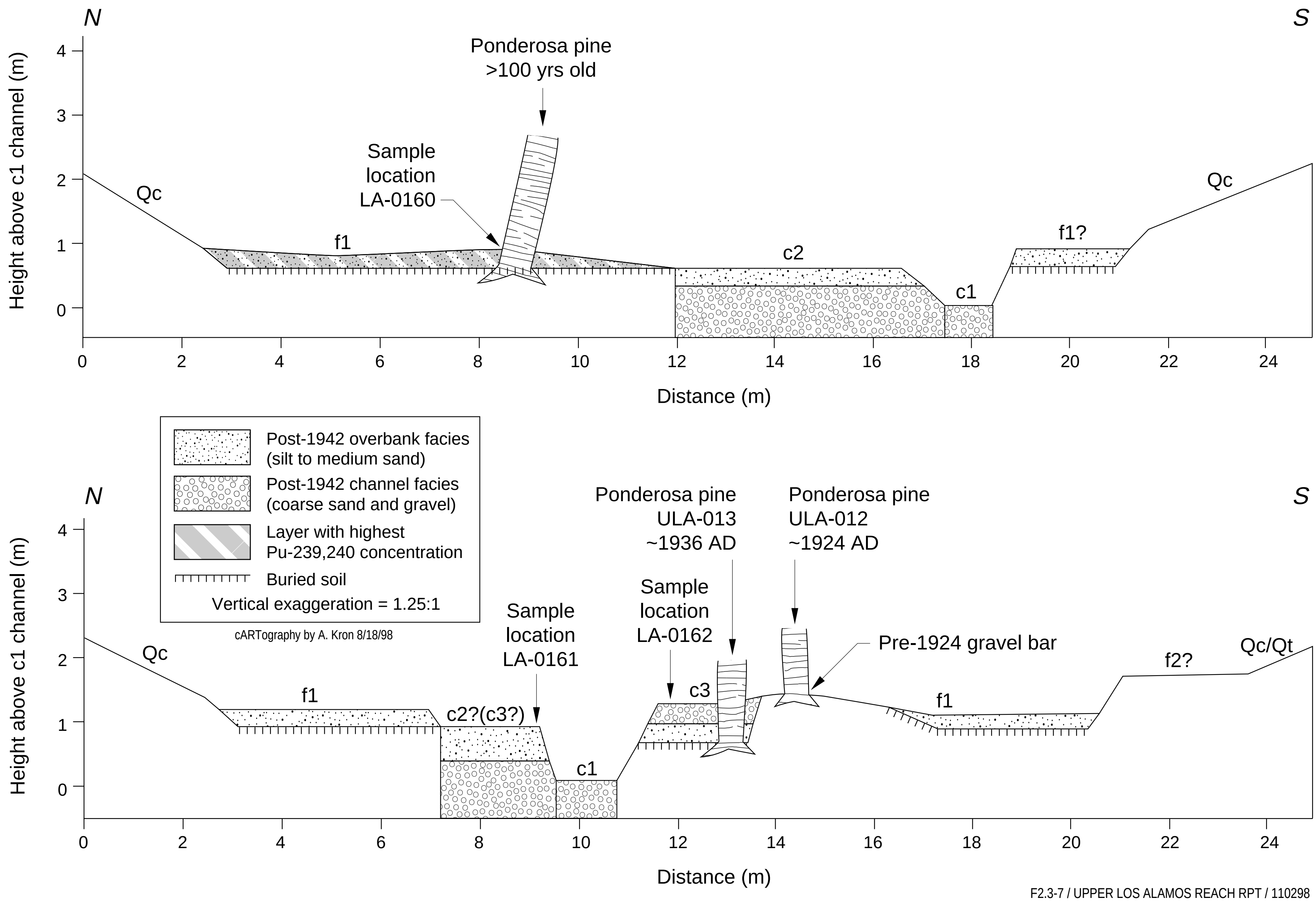

Figure 2.3-7. Schematic cross sections showing relationship between geomorphic units in reach LA-1 East.

TABLE 2.3-1

GEOMORPHIC MAPPING UNITS IN REACH LA-1

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width[a] (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
LA-1 Far West[b]	c1	[b]	198	1.8	Channel	[b]	[b]	[b]	Active channel
	c2	[b]	223	2.0	Overbank	[b]	[b]	[b]	Younger abandoned post-1942 channel
					Channel	[b]	[b]	[b]	
	c3	[b]	318	2.9	Overbank	[b]	[b]	[b]	Older abandoned post-1942 channel
					Channel	[b]	[b]	[b]	
	f1	[b]	514	4.7	Overbank	[b]	[b]	[b]	Active floodplain
	f2	[b]	514	4.7	Overbank	[b]	[b]	[b]	Potentially active floodplain
						[b]	[b]	[b]	
LA-1 West+[b]	c1	[b]	198	1.4	Channel	[b]	[b]	[b]	Active channel
	c2	[b]	108	0.8	Overbank	[b]	[b]	[b]	Younger abandoned post-1942 channel
					Channel	[b]	[b]	[b]	
	c3	[b]	334	2.4	Overbank	[b]	[b]	[b]	Older abandoned post-1942 channel
					Channel	[b]	[b]	[b]	
	f1	[b]	563	4.0	Overbank	[b]	[b]	[b]	Active floodplain
	f2	[b]	514	3.7	Overbank	[b]	[b]	[b]	Active floodplain
LA-1 West	c1	0	715	1.9	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c2	0.4	294	0.8	Overbank	0.25 ± 0.14	Fine sand	Sandy loam	Younger abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly sand	
	c3	0.6	1610	4.4	Overbank	0.42 ± 0.22	Fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	f1	0.9	2781	7.5	Overbank	0.24 ± 0.16	Very fine sand	Sandy loam	Active floodplain

a. Average unit width uses lengths of 110 m for LA-1 Far West, 140 m for LA-1 West+, 370 m for LA-1 West, 390 m for LA-1 Central, and 430 m for LA-1 East.

b. Characteristics assumed to be the same as in LA-1 West.

TABLE 2.3-1 (continued)

GEOMORPHIC MAPPING UNITS IN REACH LA-1

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
LA-1 Central	c1	0	681	1.7	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c1b	0.2	29	0.1	Channel	<1.0	?	?	Part of active channel during large floods
	c2	0.5	806	2.1	Overbank	0.31 ± 0.14	Very fine sand	Sandy loam	Younger abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	c3	1.0	740	1.9	Overbank	0.22 ± 0.21	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	<1.0	Coarse sand		Gravelly sand
	f1	1.1	2953	7.6	Overbank	0.11 ± 0.09	Very fine sand	Sandy loam	Active floodplain
	f2	1.2	1269	3.3	Overbank	<0.05	Very fine sand?	Sandy loam?	Potentially active floodplain
LA-1 East	c1	0	596	1.4	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c2	0.4	1202	2.8	Overbank	0.30 ± 0.14	Fine sand	Sandy loam	Younger abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly sand	
	c3	0.8	967	2.2	Overbank	0.25 ± 0.18	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	f1	0.9	3373	7.8	Overbank	0.21 ± 0.14	Coarse silt	Loam	Active floodplain
	f2	1.1	1456	3.4	Overbank	<0.05	Very fine sand?	Sandy loam?	Potentially active floodplain

*Average unit width uses lengths of 110 m for LA-1 Far West, 140 m for LA-1 West+, 370 m for LA-1 West, 390 m for LA-1 Central, and 430 m for LA-1 East.

2.3.1.3 Geomorphic History

Geomorphic processes within reach LA-1 since 1942 have included the lateral migration of the active channel within an area that averages 5 to 7 m wide, represented by the width of the c1, c2, and c3 units, and the occasional overtopping of higher pre-1943 surfaces during floods. Some vertical changes in the elevation of the stream bed have occurred in LA-1, resulting in young (post-1942) overbank facies sediments in some places occurring below the elevation of the present channel and channel gravels occurring up to 1.0 m above the present channel. The largest vertical changes in channel elevation are recorded by c3 gravel bars in LA-1 Central and LA-1 East that probably record local aggradation during one or more floods (e.g., Figures 2.3-6 and 2.3-7). These gravel bars commonly contain rounded concrete, indicating that they postdate initial development of TA-2 and TA-41, and tree-ring dating at a c3 gravel bar in LA-1 Central indicates deposition sometime after 1961 (Figure 2.3-6).

The post-1942 overbank facies sediment and associated contaminants present within LA-1 are stored within both the c2 and c3 units relatively close to the active channel and the f1 units farther away from the channel. The sediments contained within the c2 and c3 units are particularly susceptible to remobilization by lateral bank erosion during floods, and the average residence time for sediment at these sites is probably less than 50 years and may be less than 30 years. This conclusion is based in part on the similarity in unit characteristics between LA-1 and LA-2 and evidence for sediment residence times in LA-2 provided by isotopic ratios (Section 2.3.2.2). Approximately 40 to 60% of the overbank sediments in the different subreaches are stored on floodplain surfaces that have average residence times of greater than 50 years and are less susceptible to remobilization by bank erosion during floods. Trees older than 100 years are common on the floodplains, and average sediment residence times in these areas similarly exceed 100 years. The floodplain areas are most likely to be subjected to occasional overtopping during large floods, resulting in the deposition of additional fine-grained sediment.

2.3.2 Reach LA-2

2.3.2.1 Physical Characteristics

Reach LA-2 is in a part of upper Los Alamos Canyon where the canyon is somewhat wider than in LA-1, but where the canyon floor is still relatively narrow. LA-2 West and LA-2 East are contiguous subreaches that are divided by the confluence with DP Canyon. The area that has been impacted by post-1942 floods averages approximately 15 m wide in LA-2 West and 10 m wide in LA-2 East. The areal distribution of the geomorphic units is shown on Figures 1.3-2, 2.3-8, and 2.3-9, and topographic relations are illustrated in the cross sections of Figures 2.3-10 and 2.3-11. Physical characteristics of the geomorphic units in LA-2 are summarized in Table 2.3-2. Data on particle size and unit thickness are presented in Table B3-2, Table B3-5, and Figure B2-4.

The active channel, c1, averages 1.5 to 2 m wide in both LA-2 West and LA-2 East and has a bed composed of coarse sand and gravel. The active channel is usually bordered by abandoned post-1942 channel units (c2, c3) that average approximately 5.5 to 7.5 m in combined width and have average heights of 0.6 to 1.2 m above the channel. The characteristics of the abandoned channel units vary between LA-2 West and LA-2 East (Table 2.3-2), in part related to inputs of sediment from DP Canyon. In both subreaches c2 is a relatively low abandoned channel unit that almost continuously borders the channel, but the width of this unit doubles between LA-2 West and LA-2 East, from approximately 2.5 m to 5 m. In addition, the thickness of relatively fine-grained overbank sediments that cap these units also doubles from approximately 0.25 m to 0.5 m, and the typical particle size increases from very fine sand to fine sand at the confluence with DP Canyon. Unit c2b is a subdivision of the c2 unit in LA-2 East that is distinguished by the relatively higher levels of gamma radiation than typical c2 units, as discussed in Section 2.2.2.2.

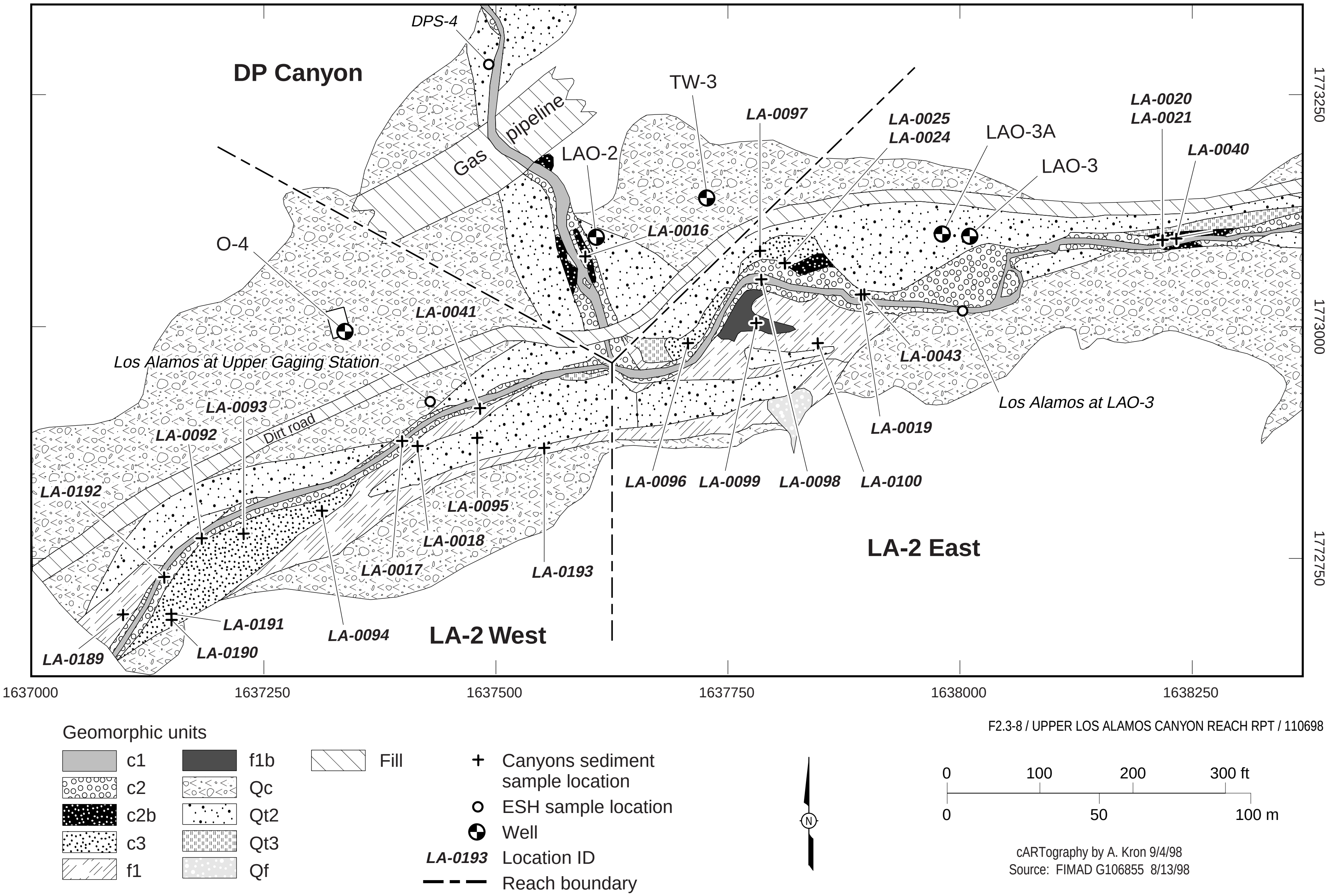

Figure 2.3-8. Geomorphic map showing sample locations in the west half of reach LA-2, including reach LA-2 West, lower DP Canyon, and part of LA-2 East.

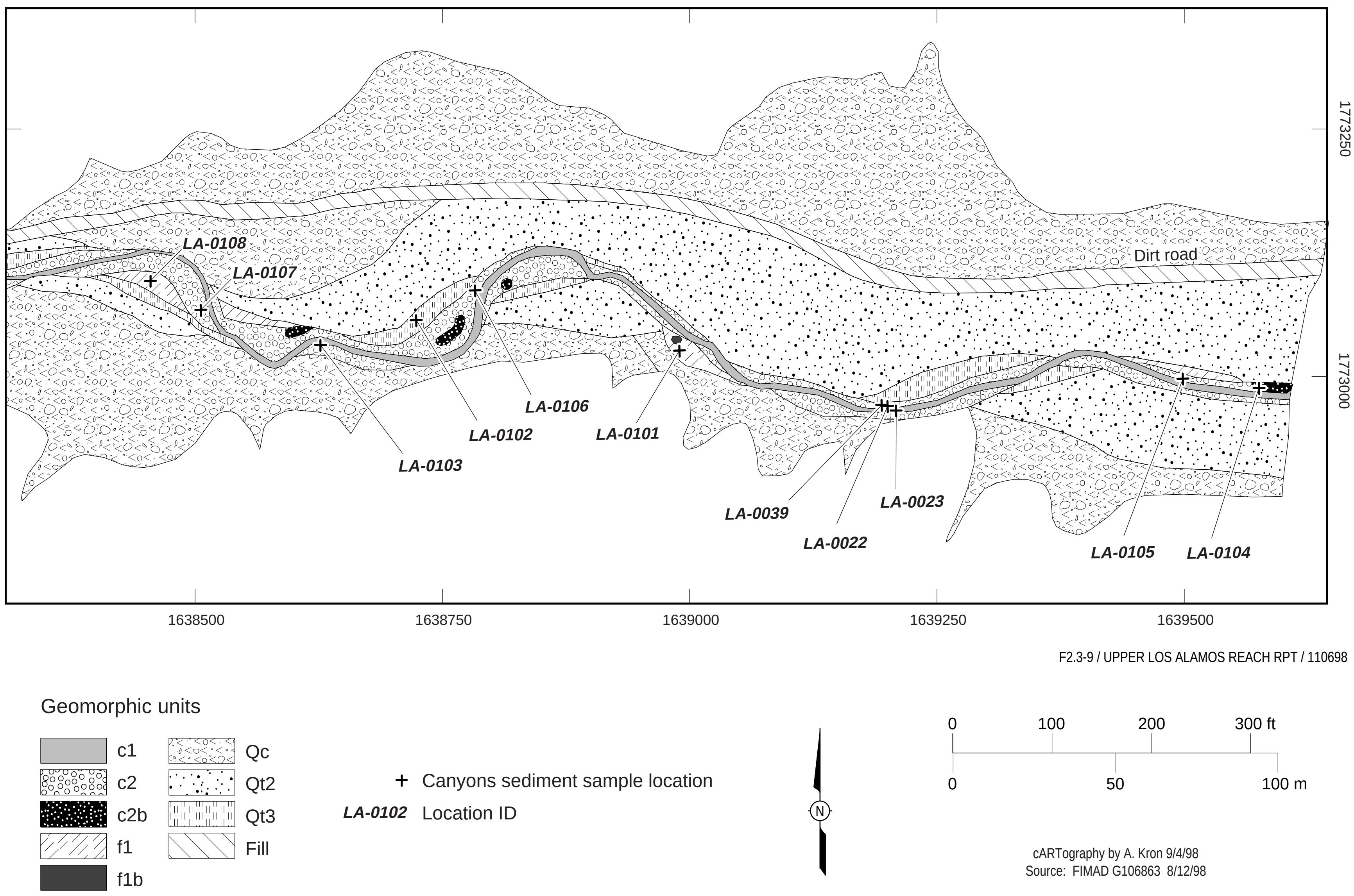

Figure 2.3-9. Geomorphic map showing sample locations in east half of reach LA-2, within LA-2 East.

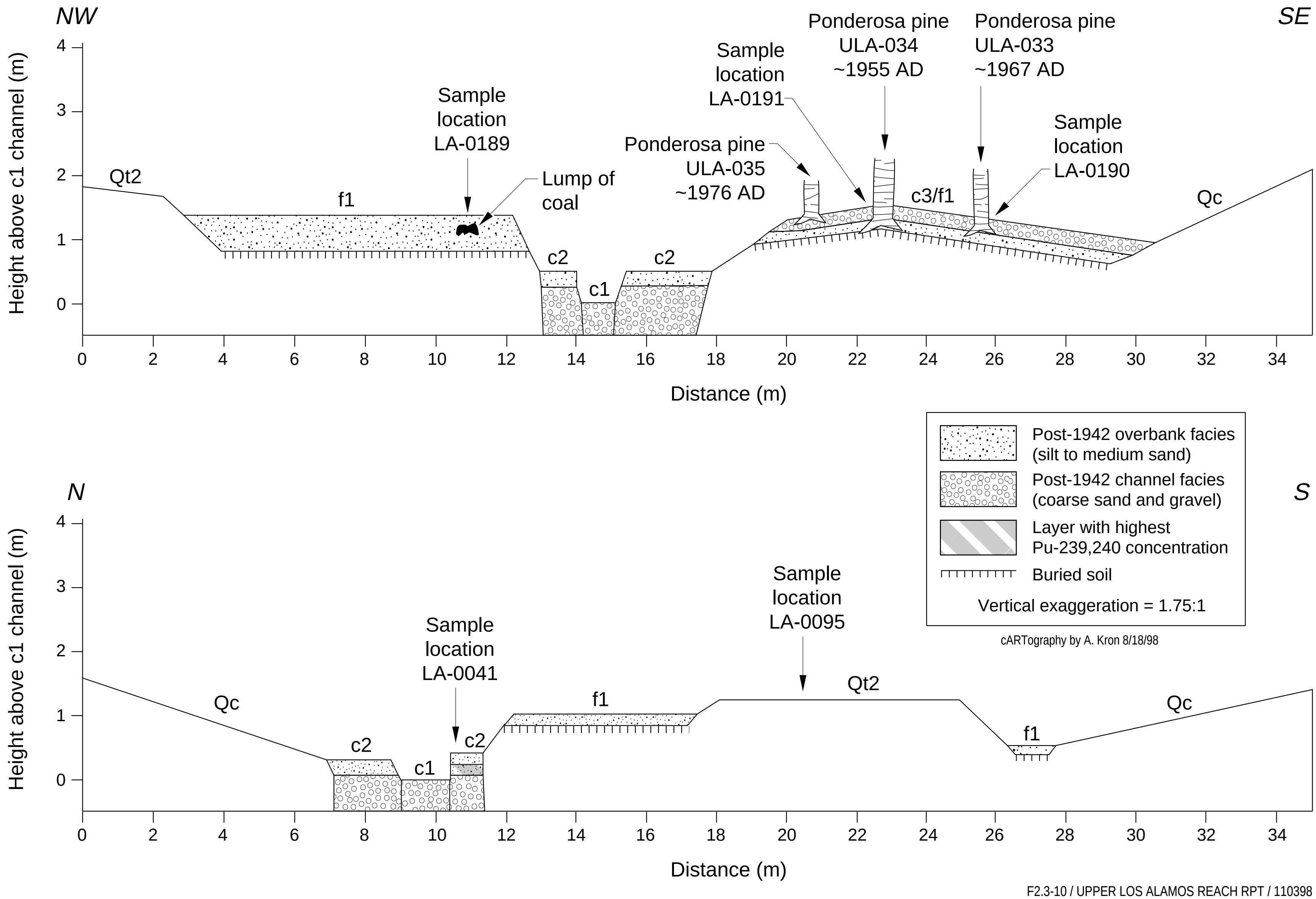

Figure 2.3-10. Schematic cross sections showing relationship between geomorphic units in reach LA-2 West.

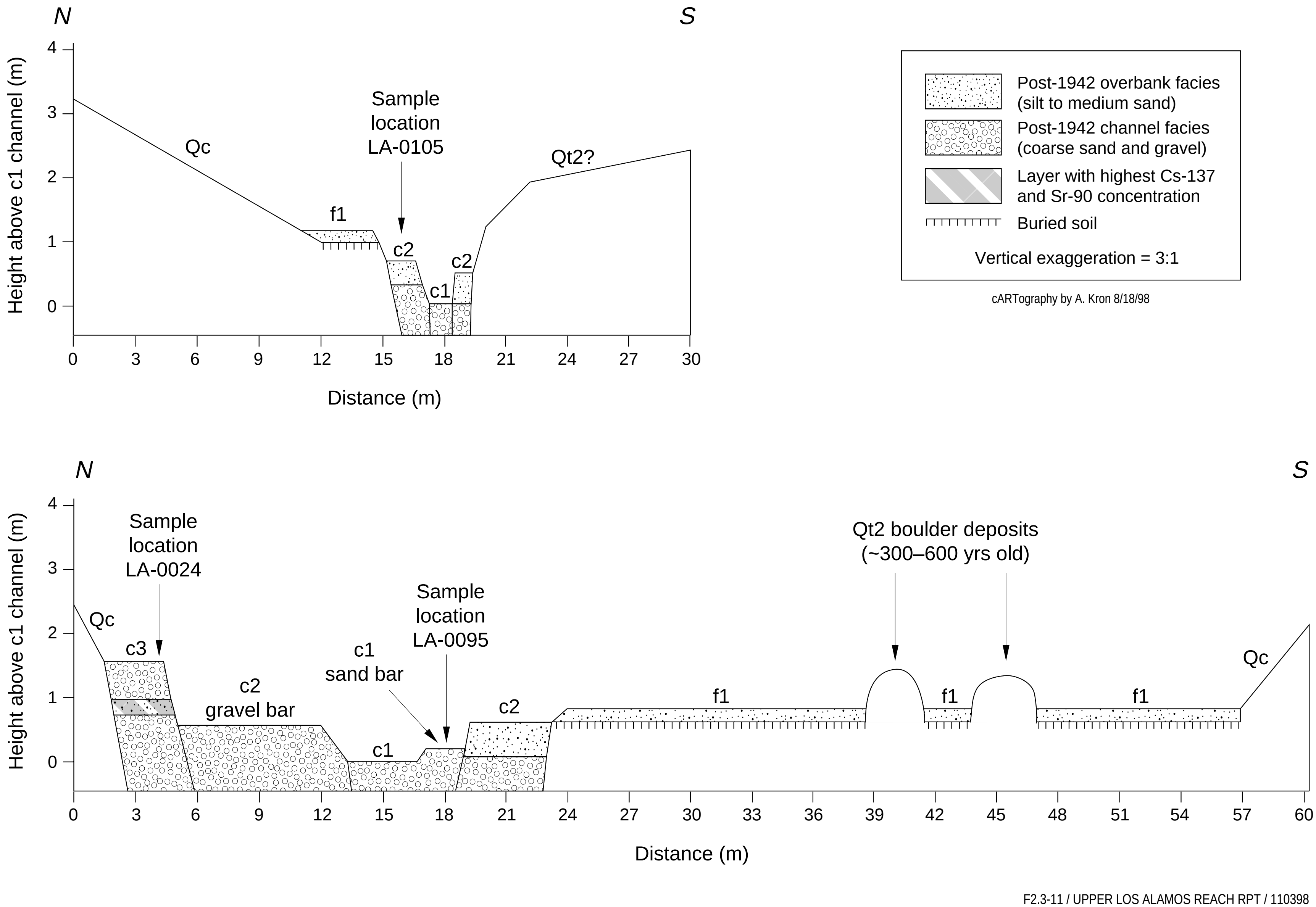

Figure 2.3-11. Schematic cross sections showing relationship between geomorphic units in reach LA-2 East.

TABLE 2.3-2

GEOMORPHIC MAPPING UNITS IN REACH LA-2

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
LA-2 West	c1	0	349	1.7	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c2	0.6	510	2.4	Overbank	0.24 ± 0.10	Very fine sand	Sandy loam	Younger abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	c3	1.1	1008	4.8	Overbank	0.05 ± 0.05	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	<1.0	Medium sand	Gravelly sandy loam	
	f1	1.0	1296	6.2	Overbank	0.15 ± 0.11	Very fine sand	Sandy loam	Active floodplain
LA-2 East	c1	0	1321	1.9	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c2	0.7	3290	4.8	Overbank	0.49 ± 0.21	Fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	c2b	0.7	223	0.3	Overbank	0.55	Fine sand	Sandy loam	Abandoned post-1942 channel with intermediate concentrations of cesium
					Channel	<1.0	Coarse sand	Gravelly loamy sand	
	c3 NE	1.2	173	0.3	Channel	0.65	Coarse sand	Sand	Abandoned post-1942 channel with highest concentrations of cesium
					Overbank	0.15	Very fine sand	Gravelly sandy loam	
					Channel	<1.0	Coarse sand	Gravelly sand	
	c3 SW	1.2	126	0.2	Overbank?	0.15	Medium sand	Gravelly loamy sand	Area closely related to c3 ne but with thinner sediments (related to f1b?)
					Overbank	0.15	Fine sand	Sandy loam	
	f1	1.2	1784	2.6	Overbank	0.15 ± 0.11	Very fine sand	Sandy loam	Active floodplain
	f1b	1.2	174	0.3	Overbank	0.15	Coarse silt	Sandy loam	Active floodplain with highest concentrations of cesium; related to c3

*Average unit width uses lengths of 210 m for LA-2 West and 680 m for LA-1 East.

The c3 units also differ between LA-2 West and LA-2 East. The c3 unit in LA-2 West consists of a relatively wide post-1942 gravel deposit that buried a large area of floodplain and which is capped by a thin layer of relatively fine-grained overbank sediment (Figure 2.3-10). In contrast, the c3 unit in LA-2 East is relatively narrow and is restricted to the west part of the subreach, within 90 m of DP Canyon (Figure 2.3-11). The c3 unit in LA-2 East is defined by areas with the highest field gamma radiation measurements in Los Alamos Canyon and consists of two discrete areas with different sediment characteristics but with similar levels of gamma radiation at the surface. The larger northeast area (c3 NE) consists of thick coarse-grained channel facies sediment deposits with a thin (0.2 m) buried overbank sediment layer where the highest concentrations of cesium-137 and strontium-90 were measured (Figure 2.3-11); this area was chosen for a study in 1996 on the uptake of contaminants by garden vegetables (Fresquez et al. 1997, 58929; Fresquez et al. 1998, 58972). The smaller southwest area (c3 SW) has a thin (0.15 m) surface layer with radionuclide concentrations similar to those found in the buried layer in the northeast c3 unit and particle size characteristics intermediate between typical channel facies and overbank facies sediment (medium sand); below this is a fine-grained overbank facies sediment layer with radionuclide levels that are much lower, although still elevated. The southwest c3 unit represents a flood levee that could be defined as a floodplain unit but is considered to represent an abandoned channel unit here for convenience because of its radiological characteristics. Both parts of the c3 unit in LA-2 East are probably dominated by sediment derived from floods from DP Canyon.

Active floodplains (f1) in LA-2 average approximately 6 m wide in LA-2 West and 3 m wide in LA-2 East (Table 2.3-2). The larger widths in LA-2 West are associated with the large c3 gravel deposits. The f1 unit averages 1.0 to 1.2 m above the active channel and is capped by an average of 0.05 m of overbank sediments dominated by very fine sand in LA-2 West and an average of 0.15 m of very fine sand in LA-2 East. An f1b subunit is distinguished in LA-2 East based on relatively high field gamma radiation measurements; the f1b unit is located close to the c3 units and probably represents sediments deposited from the same floods that deposited the c3 sediments. The area of the f1b unit in LA-2 East and the f1 unit in LA-2 West includes large boulder deposits that are designated unit Qt2 and that represent deposits from an exceptionally large flood that occurred approximately 300 to 600 years ago, as shown by radiocarbon dating (Reneau and McDonald 1996, 55538).

2.3.2.2 Radiological Characteristics

The gross gamma radiation walkover survey and fixed-point radiation measurements in reach LA-2 West indicated that levels of alpha-, beta-, and gamma-emitting radionuclides were not high enough to allow contaminated areas to be distinguished from background radiation in LA-2 West. Therefore, field radiation measurements were not used in the geomorphic mapping in LA-2 West or to help select sample sites. The gross gamma radiation walkover measurements are presented in Figure 2.3-12, and a summary of the field radiation measurements in LA-2 West are presented in Appendix B-4.0.

The gross gamma radiation walkover surveys in reach LA-2 East indicated that levels of gamma-emitting radionuclides downstream from DP Canyon were high enough to allow precise mapping of the horizontal extent of these radionuclides (Figures 2.3-12 and 2.3-13). Therefore, these measurements were used both to refine the preliminary geomorphic map and to subdivide areas in LA-2 East on the basis of variations in gross gamma radiation. In addition, fixed-point gamma radiation measurements were used to examine vertical variations in gamma-emitting radionuclides within the geomorphic units and to select specific sample layers. The fixed-point gamma radiation data are presented in Appendix B-4.0, including depth profiles of gamma radiation in a series of stratigraphic sections through the c2, c2b, and c3 units (Figure B4-5). The fixed-point beta radiation measurements also showed levels above background values, but beta radiation was strongly correlated with gamma radiation (Figure B4-4) and these measurements provided no additional useful information. The fixed-point alpha radiation measurements did not reveal alpha radiation above background values. The fixed-point alpha and beta radiation measurements are presented in Appendix B-4.0.

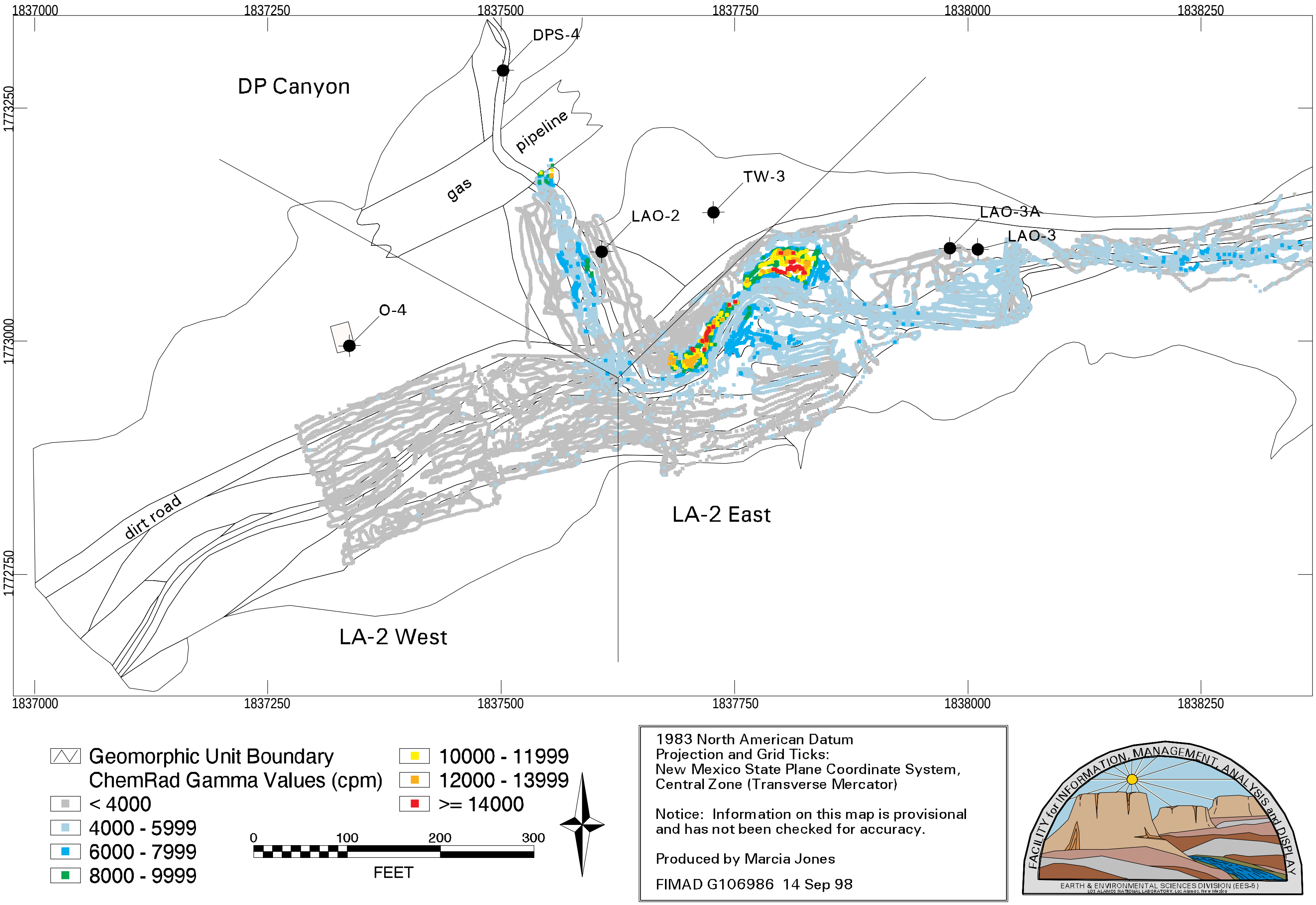

Figure 2.3-12. Map showing gross gamma radiation walkover measurements in west half of reach LA-2, including reach LA-2 West, lower DP Canyon, and part of LA-2 East.

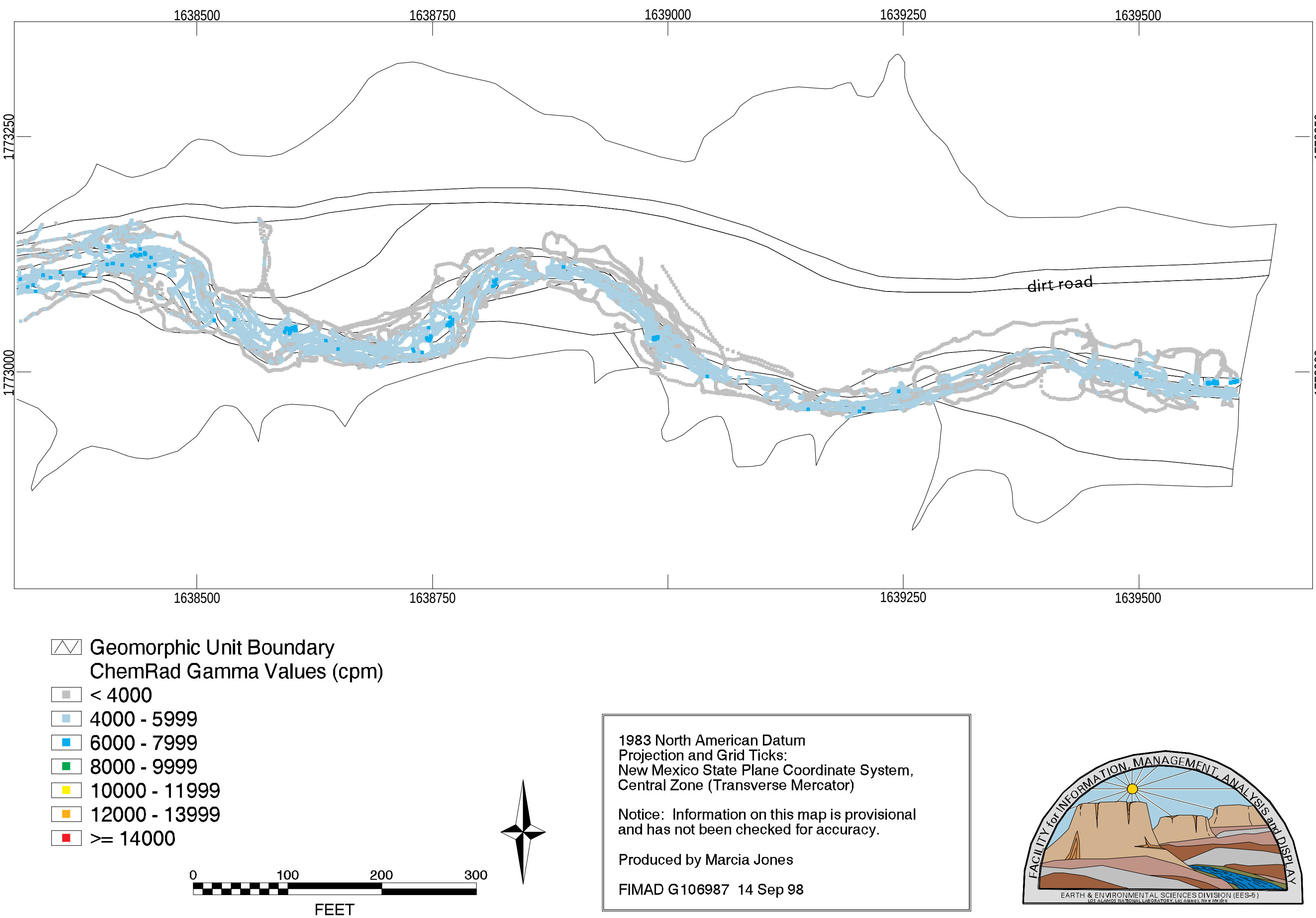

Figure 2.3-13. Map showing gross gamma radiation walkover measurements in east half of reach°LA-2, within LA-2 East.

The gross gamma radiation walkover measurements in LA-2 East indicated that the highest levels of gamma radiation occur in two nearby areas 20 to 90 m downstream from the confluence with DP Canyon (Figure 2.3-12), which were designated c3 SW and c3 NE. Gross gamma measurements by CHEMRAD (from Oak Ridge, Tennessee) with 1-second count times and an unshielded probe were typically 8000 to 15,000 counts per minute (cpm) in the c3 units, with a maximum measurement of 16,700 cpm. In comparison, typical gamma radiation values upstream from DP Canyon in LA-2 West were 2000 to 4000 cpm, which represents local background radiation; typical values in the widespread c2 unit downstream from DP Canyon are 4000 to 6000 cpm. The gross gamma walkover measurements also indicated small areas with intermediate levels of gamma radiation, which were designated c2b and f1 b. The c2b unit includes areas that have the same physical characteristics as the typical c2 unit but where gamma radiation was typically 5000 to 8000 cpm. The f1b unit is a floodplain that is located across the channel from the c3 unit and where gamma radiation was typically 6000 to 8000 cpm.

The fixed-point gamma radiation measurements in LA-2 East were mostly from vertical exposures in the stream banks and were used to define vertical variations in gross gamma radiation. These measurements used 1-minute count times and a shielded probe. The shielded probe focuses the measurements on the specific sediment layer of interest better than the unshielded probe used for the walkover survey, although the measurements are still affected by gamma radiation derived from nearby layers. Measurements with the shielded probe are also made near the soil surface instead of at a height of approximately 0.3 m. Therefore, these measurements cannot be directly compared, although they show the same relative differences in gamma radiation.

The fixed-point gamma radiation measurements show that in most units the highest levels of radiation occur in the subsurface, and these subsurface layers generally correspond to the finest-grained sediment within individual stratigraphic sections. The relations of variations in radionuclide concentration and sediment particle size is discussed further in Section 3.3.3. Figure 2.3-14 shows average variations in gamma radiation through the c2, c2b, and c3 units, combining measurements from all vertical sections in each unit (the individual depth profiles are shown in Figure B4-5, and the complete set of fixed-point measurements is presented in Table B4-1). In the c3 unit, average gamma radiation increases with depth from approximately 18,000 cpm at the surface to an average of approximately 42,500 cpm at a depth of 0.7 m; the maximum value obtained in this unit was 46,701 cpm from a depth of 0.7 m at section LA2-S4 (sample location LA-0024). In the c2b unit, average gamma radiation increases with depth from approximately 12,500 cpm at the surface to an average of approximately 20,000 cpm at a depth of 0.5 m; the maximum value obtained in this unit was 24,480 cpm from a depth of 0.7 m at section LA2-S11 (sample location LA-0020). In the c2 unit, average gamma radiation increases with depth from approximately 10,000 cpm at the surface to an average of approximately 11,500 cpm at a depth of 0.3 m; the maximum value obtained in this unit was 12,897 cpm from a depth of 0.5 m at section LA2-S13 (sample location LA-0107). In contrast, the highest measurement obtained with this instrument in LA-2 West, upstream from DP Canyon, was 6955 cpm from the c2 unit (fixed-point site LA2-81). Measurements in LA-2 West provide an approximate upper limit of local background gamma radiation because of the general absence of gamma-emitting radionuclides above background values (Section 3,3,3) . Gamma radiation in the c1 unit in LA-2 East overlaps with the background range, with a maximum of 7693 cpm at fixed- point site LA2-61 (sample location LA-0023) and a minimum of 6155 cpm at fixed-point site LA2-33.

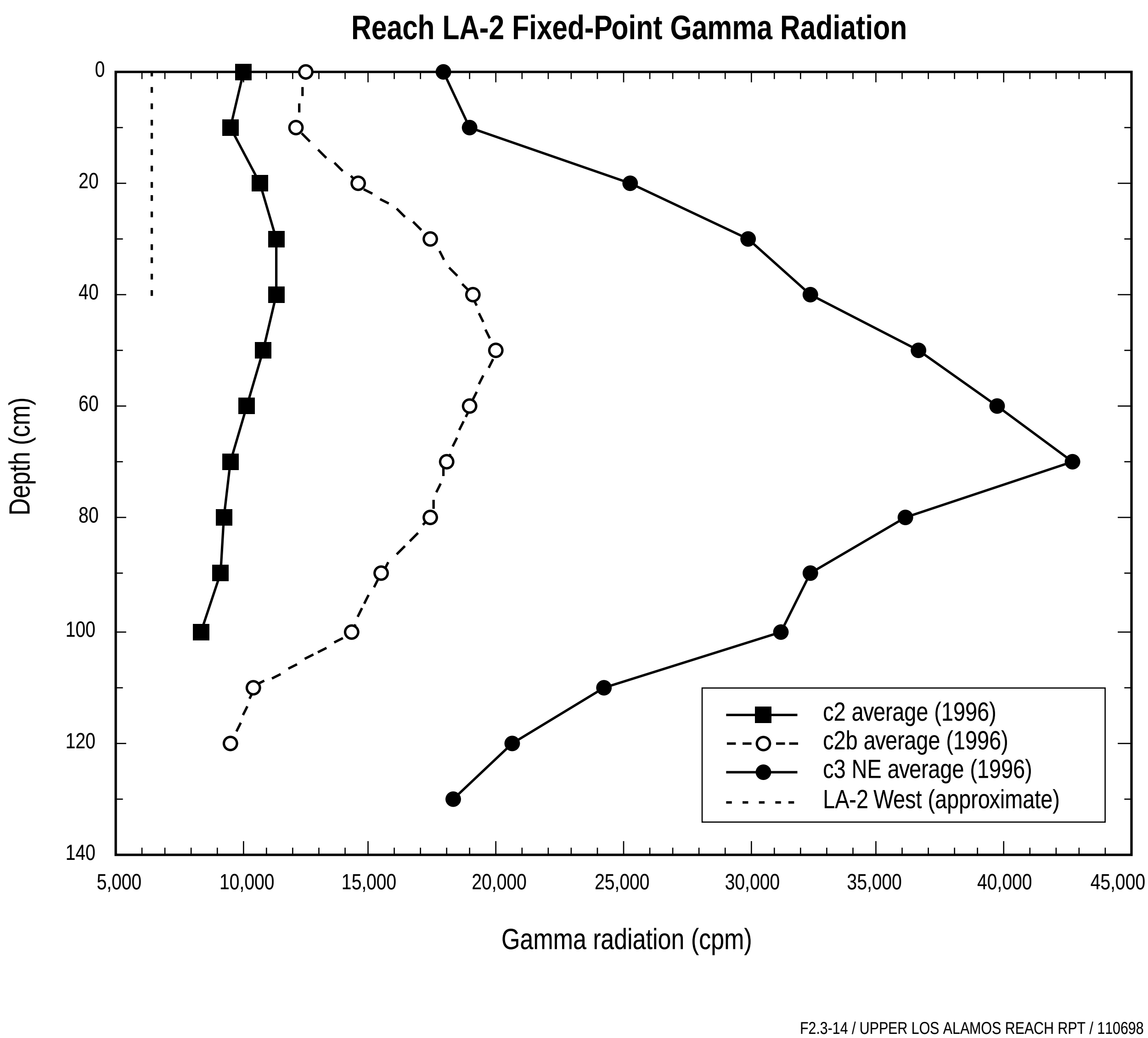

Figure 2.3-14. Plots of average gross gamma radiation against depth for sections from the c2, c2b, and c3 units in reach LA-2 East.

2.3.2.3 Geomorphic History

Geomorphic processes within reach LA-2 since 1942 have included the lateral migration of the active channel within an area that averages approximately 4 m wide in LA-2 West and 7 m wide in LA-2 East and the occasional overtopping of higher pre-1943 surfaces during floods. The c3 units in both LA-2 West and LA-2 East represent distinct aggradational periods, periods when the stream bed rose because of the deposition of significant amounts of channel facies sediment, although the nature and timing of these depositional periods was apparently different between the subreaches. In LA-2 West, the c3 aggradation is represented by wide gravel bars that were deposited over the former floodplain surface, and tree-ring dating indicates gravel deposition between 1967 and 1976 (trees ULA-033 and ULA-035, Table B1-1 and Figure 2.3-10). Similar gravel bars also occur in the c3 units of LA-1 Central and LA-1 East (Section 2.3.1.3). In contrast, the c3 unit in LA-2 East is dominated by channel sands and apparently records deposition from one or more large floods that emanated from DP Canyon between 1956 and 1968. The c3 unit in LA-2 East has the highest concentrations of radionuclides derived from the 21-011(k) outfall and released into DP Canyon (with recorded releases beginning in 1956), and the isotopic ratios in these sediments indicates that the sediment predates 1968 (as discussed in Section 3.3.3.2). The c3 unit in LA-2 West is presently isolated from the active channel and is relatively stable, but the c3 unit in LA-2 East is mostly located on the outside of a sharp bend in the channel and is very susceptible to bank erosion during large floods.

The c2 unit in LA-2 East provides a record of the dominant processes of erosion and deposition that have occurred in this part of upper Los Alamos Canyon since 1968 when there was a major increase in the use of plutonium-238 at the Laboratory (Nyhan et al. 1975, 11746; Nyhan et al. 1976, 11747). The history of the c2 unit in LA-2 West is probably similar to that in LA-2 East, although age control is poor in LA-2 West. The elevation of the stream bed has been relatively stable during this period, located within 0.5 m of its current elevation as indicated by the height of buried channel gravels relative to the present channel. In contrast to this apparent vertical stability, available data indicate that lateral erosion is common. Specifically, isotopic ratios in the c2 overbank sediments show that most of these sediments were deposited after 1978 when discharge of americium-241 increased at the 21-011(k) outfall (Section 3.3.1.5). Age control provided by isotopic ratios suggest that the c2 unit contains only small volumes of overbank sediment deposited between 1968 and 1978, dominantly in the areas mapped as c2b, and contains even smaller volumes of sediment deposited before 1968. Hence, the average residence time of overbank sediment in these locations is apparently less than 20 years, and remobilization of most of this sediment by lateral bank erosion could occur in similar time frames. Only small volumes of the fine-grained overbank facies sediment is located on the more stable floodplain surfaces.

Significant changes in the character of the c2 unit in LA-2 occurs at the confluence of DP and Los Alamos Canyons, which indicates that DP Canyon is a major sediment source for Los Alamos Canyon and that floods derived from this tributary also influence erosion rates in Los Alamos Canyon. The average thickness of overbank sediment on the c2 unit roughly doubles at this location, averaging 24 cm upstream and 49 cm downstream (Table 2.3-2), and this increased thickness probably records deposition of sediment derived from DP Canyon. The decrease in channel gradient and the decrease in confinement that occur when floods exit the steep and narrow lower part of DP Canyon would both contribute to deposition of sediment downstream from the confluence. The width of the c2 unit also increases downstream from DP Canyon, which may indicate greater rates of lateral bank erosion downstream from the confluence caused by floods that emanate from DP Canyon. Field observations indicate that floods commonly occur in DP Canyon when Los Alamos Canyon upstream from the confluence is not flooding, and runoff from paved areas in the Los Alamos townsite in the headwaters of DP Canyon is believed to contribute to this high flood frequency in DP Canyon.

2.3.3 Reach LA-3

2.3.3.1 Physical Characteristics

Reach LA-3 is in a part of upper Los Alamos Canyon close to state road NM 4 and the Laboratory boundary where the canyon floor is much wider than in upstream reaches but where the active part of the canyon floor is narrower. The area that has been impacted by post-1942 floods averages approximately 6.5 to 9 m wide. The areal distribution of the geomorphic units is shown on Figures 1.3-3, 2.3-15, and 2.3-16, and topographic relations are illustrated in the cross sections of Figure 2.3-17. Physical characteristics of the geomorphic units in LA-3 are summarized in Table 2.3-3. Data on particle size and unit thickness are presented in Table B3-3, Table B3-6, and Figure B2-5.

The active channel, c1, averages 2 m wide in LA-3 and has a bed composed of coarse sand and gravel. The active channel is usually bordered by abandoned post-1942 channel units (c2 and c3) that average approximately 3.5 m in combined width and have average heights of 0.4 to 0.7 m above the channel. The c2 and c3 units are usually capped by an average of approximately 0.4 to 0.55 m of relatively fine-grained overbank sediments dominated by very fine sand.

Active floodplains (f1 and f2) are relatively narrow in LA-3 and only discontinuously border the abandoned channel units. The f1 unit has an average width of only 1 m, has an average height of approximately 0.8 m, and is capped by an average of approximately 0.4 m of overbank sediment dominated by very fine sand. The f1 unit is commonly closely associated with the c3 unit and is distinguished by the pre-1943 age of the underlying channel facies sediment deposits. The f2 unit is wider, averaging approximately 2.4 m wide but is probably overlain by thin and discontinuous post-1942 overbank sediment layers. Field gamma radiation measurements are within background ranges on the f2 unit, and f2 is considered to represent a post-1942 floodplain solely on the basis of analytical data that indicate the presence of radionuclides at relatively low concentrations but above background values.

2.3.3.2 Radiological Characteristics

Based on the results of the radiological field measurements in reach LA-2 East, only gross gamma radiation walkover measurements and fixed-point measurements were made in reach LA-3. The gross gamma radiation walkover measurements in LA-3 are presented in Figures 2.3-18 and 2.3-19, all the fixed-point measurements are presented in Table B4-3, and gamma radiation depth profiles are presented in Figure B4-8.

The gross gamma radiation walkover survey indicated that levels of gamma-emitting radionuclides in reach LA-3 were much closer to background than in LA-2 East and that these measurements were less useful than in LA-2 East for defining geomorphic unit boundaries based on variations in gamma radiation. In addition, vegetation cover in the post-1942 geomorphic units in LA-3 is much denser than LA-2, often consisting of thick brush that prevented walkover measurements, and the post-1942 geomorphic units are generally narrower in LA-3 than in LA-2, which also limited the utility of this procedure. However, sites with gamma radiation above background values were clearly identified during the walkover survey, and the walkover survey helped guide the fixed-point measurements. Maximum gamma radiation measured during the walkover survey was 6840 cpm in the c3 unit, and values of 4000 to 5000 cpm were common in the c3 unit. In comparison, typical values in the c1 and c2 units were 3000 to 4500 cpm, which overlap with data from nearby colluvial slopes where measurements reached 4500 cpm.

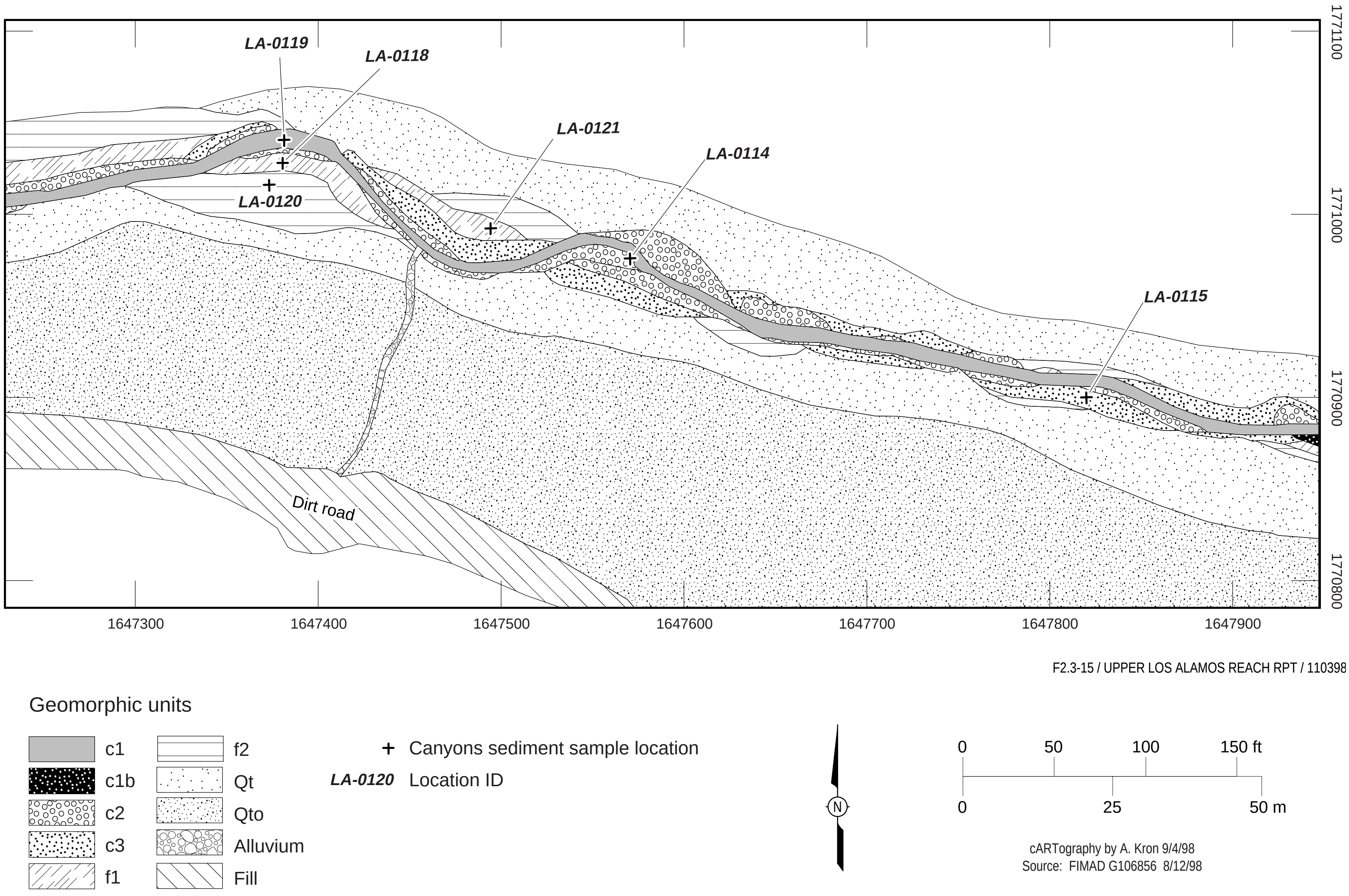

Figure 2.3-15. Geomorphic map of west half of reach LA-3 showing sample locations.

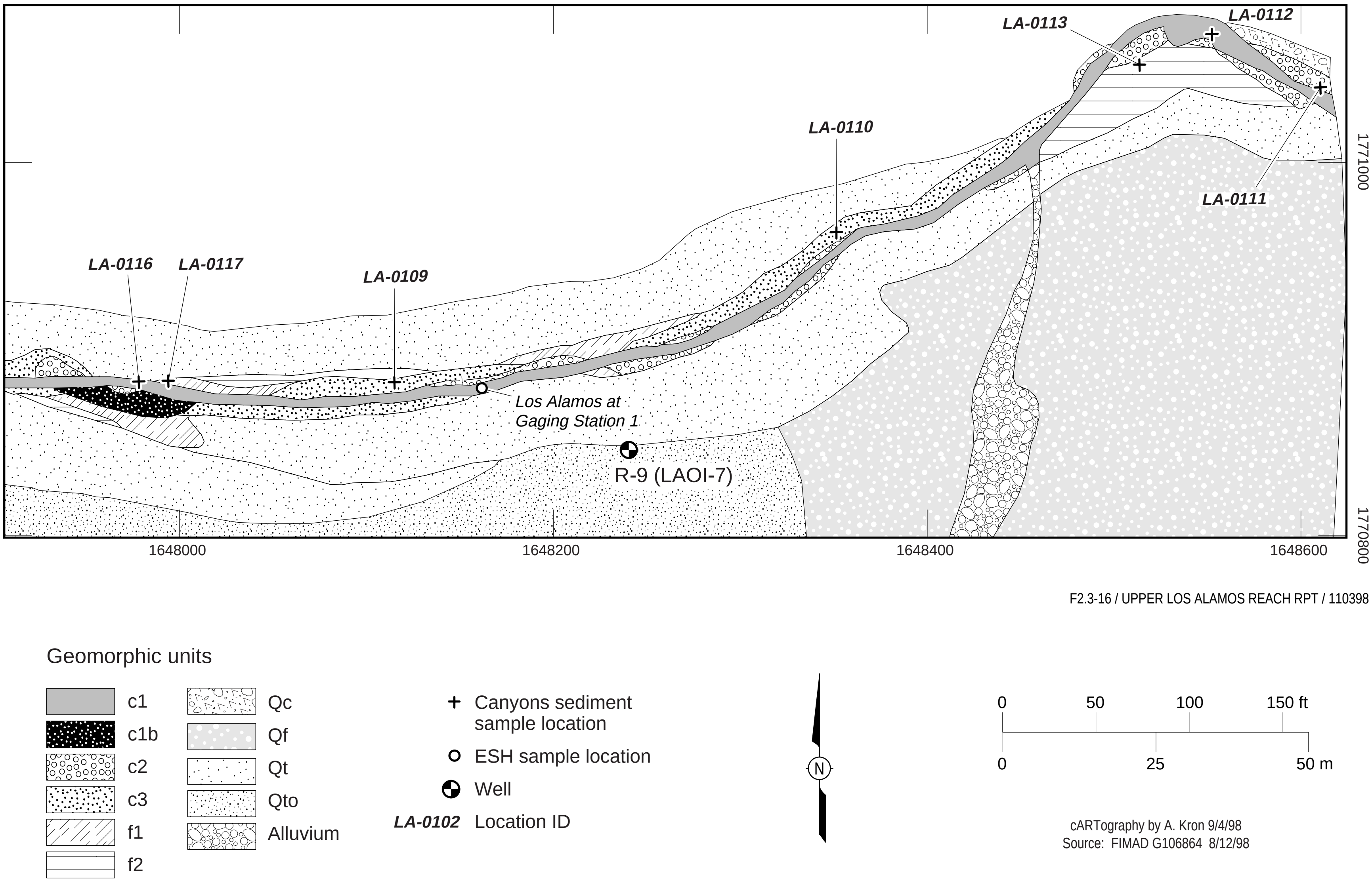

Figure 2.3-16. Geomorphic map of east half of reach LA-3 showing sample locations.

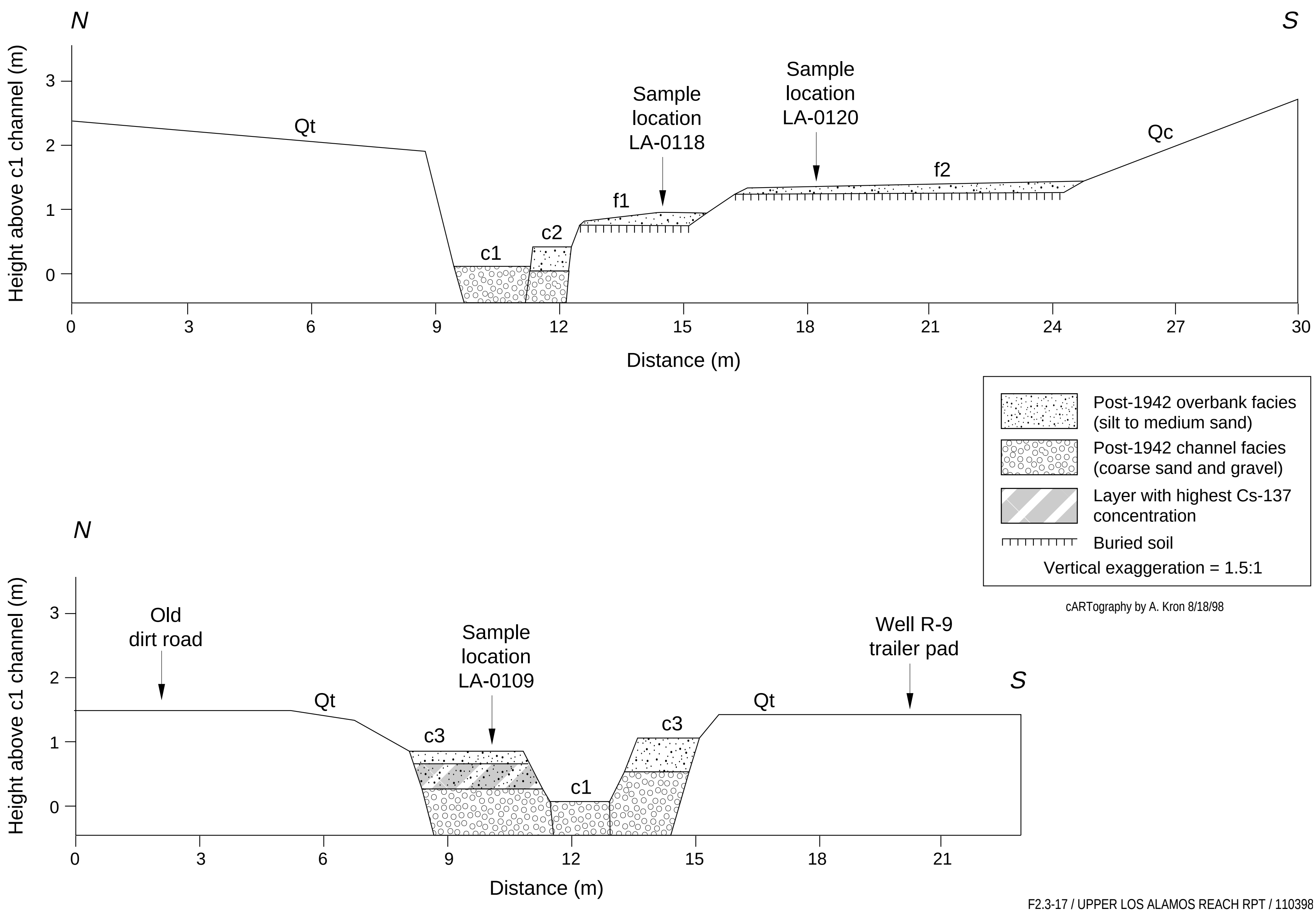

Figure 2.3-17. Schematic cross sections showing relationship between geomorphic units in reach LA-3.

TABLE 2.3-3

GEOMORPHIC MAPPING UNITS IN REACH LA-3

Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
c1	0	897	2.0	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
c1b	0.2	62	0.1	Channel	<1.0	Coarse sand	Gravelly sand	Sand and gravel bars adjacent to active channel
c2	0.4	651	1.5	Overbank	0.41 ± 0.12	Very fine sand	Sandy loam	Younger abandoned post-1942 channel
				Channel	<1.0	Coarse sand	Gravelly sand	
c3	0.7	834	1.9	Overbank	0.55 ± 0.09	Very fine sand	Sandy loam	Older abandoned post-1942 channel
				Channel	<1.0	Coarse sand	Gravelly sand	
f1	0.8	433	1.0	Overbank	0.42 ± 0.22	Very fine sand	Sandy loam	Active floodplain
f2	1.1	1034	2.4	Overbank	<0.05	Fine sand	Sandy loam	Potentially active floodplain

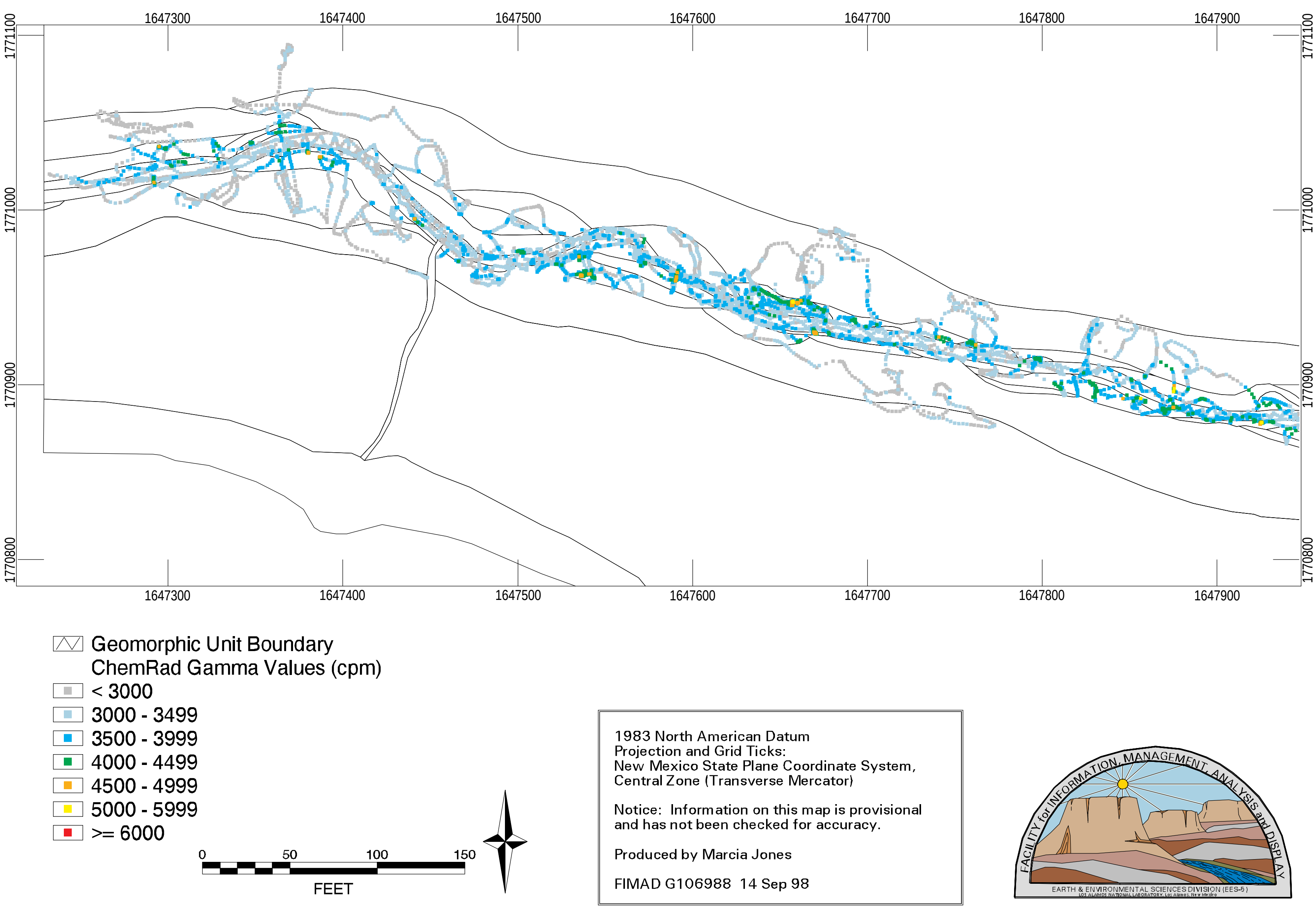

Figure 2.3-18. Map showing gross gamma radiation walkover measurements in west half of reach°LA-3.

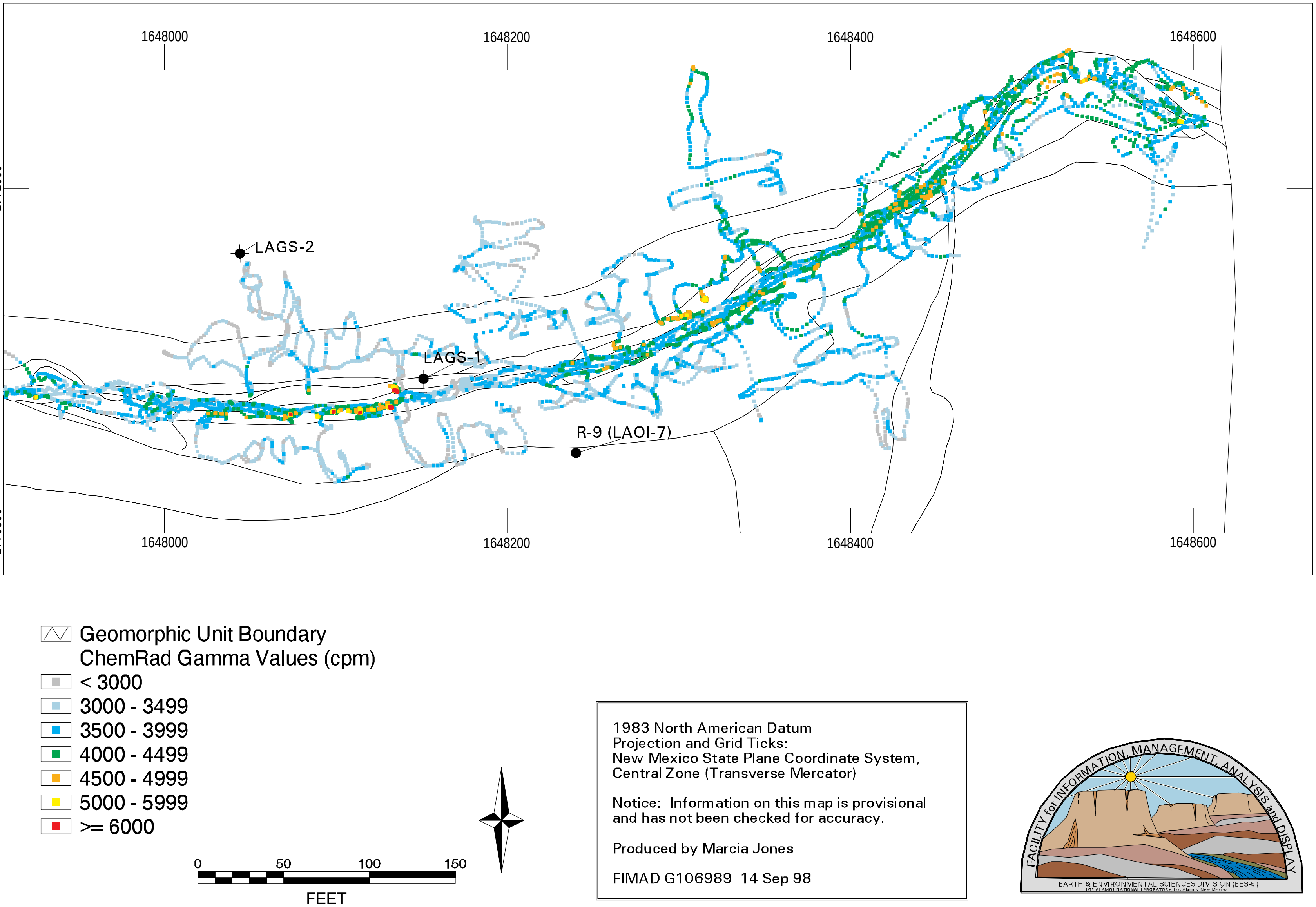

Figure 2.3-19. Map showing gross gamma radiation walkover measurements in east half of reach°LA-3.

The fixed-point gamma radiation measurements in LA-3 were mostly from vertical exposures in the stream banks and were used to subdivide the post-1942 abandoned channel units, to define vertical variations in gross gamma radiation, and to select sample sites. Plots showing gamma radiation in each vertical section (Figure B4-8) were overlaid, and profiles that had similar radiation were grouped into one of six "bins." The four bins with the highest radiation levels were assigned to the c3 unit, and the two bins with the lowest radiation levels were assigned to the c2 unit. The assigned bins for each section are indicated in Table B4-3. Sediment sampling was conducted in representative sections within three of the four c3 bins and both of the c2 bins, and the sediment layer with the highest gamma radiation in each of these five sections was chosen for full-suite analyses.

As in LA-2 East, the fixed-point gamma radiation measurements in LA-3 show that in most units the highest levels of radiation occur in the subsurface, and these subsurface layers generally correspond to the finest-grained sediment within individual stratigraphic sections. The relations of variations in radionuclide concentration and sediment particle size is discussed further in Section 3.3.4.2. Figure 2.3-20 shows average variations in gamma radiation through the c2 and c3 units, combining measurements from all vertical sections in each unit (the individual depth profiles are shown in Figure B4-8, and the complete set of fixed-point measurements is presented in Table B4-3). Average values through pre-1942 stream terraces (Qt unit) are also shown for comparison. Note that some sections were measured twice: first in late May 1997 when the stream was flowing and the sediment was relatively moist and again in late June 1997 when the stream was no longer flowing and the sediment was drier. Radiation measurements were consistently high in June (Table B4-3, Figure B4-8), consistent with less attenuation of gamma radiation occurring in the drier sediment, although the relative difference between different sections and different layers within individual sections did not change significantly. Binning was performed using the May 1997 data set for consistency, and the average values in Figure 2.3-20 also use only the May 1997 data.

In the c3 unit, average gamma radiation increases with depth from approximately 8000 cpm at the surface to an average of approximately 9300 cpm at a depth of 0.3 to 0.4 m. The maximum values obtained in c3 in May and June 1997 were both from section LA3-S5 (sample location LA-0109): 10,695 cpm from a depth of 0.4 m in May and 11,038 cpm from a depth of 0.45 m in June. In the c2 unit, average gamma radiation increases with depth from approximately 7600 cpm at the surface to an average of approximately 8000 cpm at a depth of 0.4 m. The maximum values obtained in c2 in May and June 1997 were both from section LA3-S17 (sample location LA-0111): 8546 cpm from a depth of 0.3 m in May and 9481 cpm from the same depth in June. The f1 unit has levels of gamma radiation intermediate between c2 and c3 and probably includes sediment correlative with both units. In contrast, the highest measurement obtained with this instrument in pre-1942 geomorphic units is 8131 cpm from the Qt unit (fixed-point site LA3-19, May 1997), and surface measurements averaged approximately 6900 cpm. The highest measurement obtained from the c1 unit is 7049 cpm (fixed-point site LA3-66, sample location LA-0112, June 1997), which is indistinguishable from background radiation.

2.3.3.3 Geomorphic History

Geomorphic processes within reach LA-3 since 1942 have included the lateral migration of the active channel within a narrow area that averages 5.5 m wide, represented by the width of the c1, c2, and c3 units, and the occasional overtopping of higher pre-1943 surfaces during floods. The channel location has apparently been stable, and at one site a tree that germinated circa 1924 AD is growing on a stream bank near the active channel and below a Qt stream terrace (tree ULA-001, Table B1-1; near sample site LA-0110), indicating little change in channel geometry for more than 70 years. Isotopic ratios within LA-3 overbank sediment (discussed in Section 3.3.4.2) indicate that only small volumes of sediment occur in LA-3 that were deposited between 1942 and 1968, and lateral bank erosion rates are apparently high enough that the average residence time of overbank sediment close to the active channel is less than 30 years.

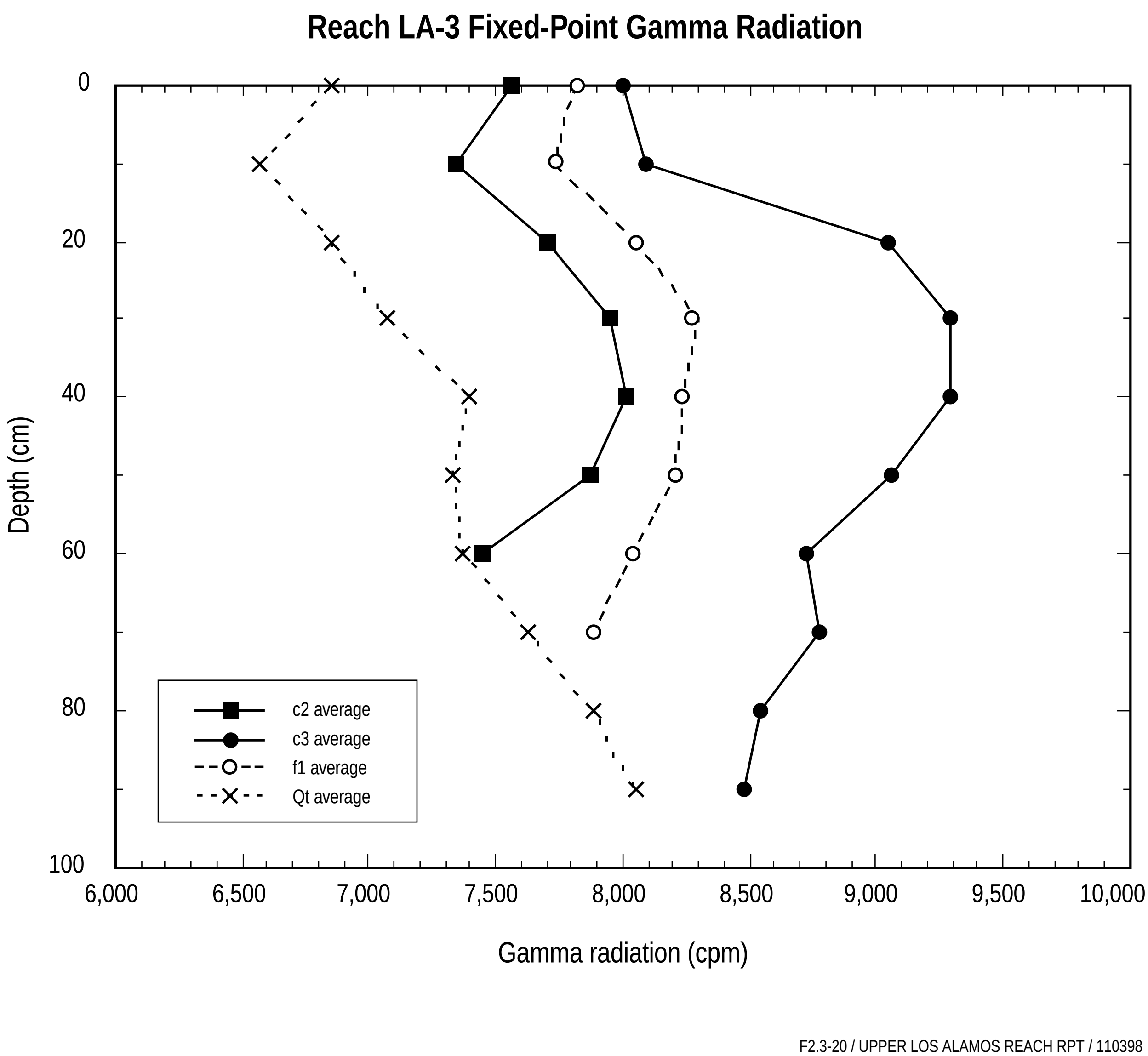

Figure 2.3-20. Plots of average gross gamma radiation against depth from the c2, c3, f1, and Qt units in reach LA-3.

This conclusion is consistent with the evidence in LA-2 East (discussed in Section 2.3.2.3), in turn suggesting that similar conditions exist between LA-2 and LA-3. Stratigraphic evidence indicates that the stream bed in LA-3 has remained within approximately 0.5 m of its present elevation during this period, which is also consistent with evidence in LA-2. The vertical stability of the stream bed in LA-3 may be aided by the occurrence of basalt in the channel bed a short distance downstream, which prevents significant channel incision over these time scales.

Floods in LA-3 since 1942 have been largely confined to the area close to the active channel, and the combined width of abandoned channel units and post-1942 floodplains in LA-3 is less than in any of the upstream reaches. This observation may indicate that floods produced in the upper parts of the watershed have attenuated by the time they reach LA-3, having lower peak discharges than upstream. The largest flood since 1942 in LA-3 may have occurred before the initial releases of cesium-137 from the 21-011(k) outfall, as indicated by a sample from the f2 unit at the east end of LA-3 (sample location LA-0113, Figure 2.3-16) that has plutonium-239,240 above the background value but cesium-137 below the background value.

2.3.4 Supplemental Characterization between Reaches

After it was recognized that gross gamma radiation walkover measurements provided a fast and efficient means to identify variations in gamma radiation within parts of upper Los Alamos Canyon, supplemental characterization between reaches was conducted in May 1996. This characterization involved the collection of gamma radiation measurements from a series of short (10 to 45 m long) sections of the active stream channel and adjacent post-1942 geomorphic units extending from the TA-2 security fence downstream to state road NM 4. The methods used in this survey are discussed further in Appendix B-4.1.1.

Gamma radiation data were collected from approximately 30% of the 7 km of Los Alamos Canyon between TA-2 and state road NM 4. Figure 2.3-21 summarizes these data, showing average values from each measurement interval for both the active channel and the adjacent surfaces where fine-grained overbank facies sediment has been deposited. Gamma radiation is relatively low between TA-2 and DP Canyon and probably records background radiation levels because of the general absence of gamma-emitting radionuclides above background values in these areas (Section 3). Gamma radiation increases dramatically at DP Canyon and then progressively decreases to state road NM 4, although radiation at the eastern end of the survey is still elevated relative to radiation upstream from DP Canyon. Gamma radiation both upstream and downstream from DP Canyon is higher on surfaces underlain by fine-grained sediment than along the active channel, and the difference is most pronounced downstream from DP Canyon. The differences between gamma radiation in coarse-grained and fine-grained sediment upstream from DP Canyon probably reflect variations in naturally occurring gamma-emitting radionuclides between these sediments, whereas the differences downstream from DP Canyon reflect fluvial segregation of cesium-137 derived from the 21-011(k) outfall superimposed on the background variations.

The gross gamma walkover radiation data reveal that although there is a general decreasing trend in radiation level from DP Canyon to state road NM 4, considerable variability can exist in any area (Figure 2.3-21). For example, data obtained approximately 1.1 to 1.5 km downstream from DP Canyon show that some areas have gamma radiation at higher levels than that measured in the typical c2 unit in LA-2 East (which extends 0.6 km downstream from DP Canyon), although radiation at other sites is lower. These data are consistent with the variability that exists in LA-2 East associated with sediment deposits of different ages and suggest that the areas of highest radiation measured farther downstream correspond to areas containing sediment equivalent in age to the c2b or c3 units in LA-2 East. Irregular variability in gamma radiation has also been identified in aerial radiological surveys of this area (Fritzsche 1990, 58971).

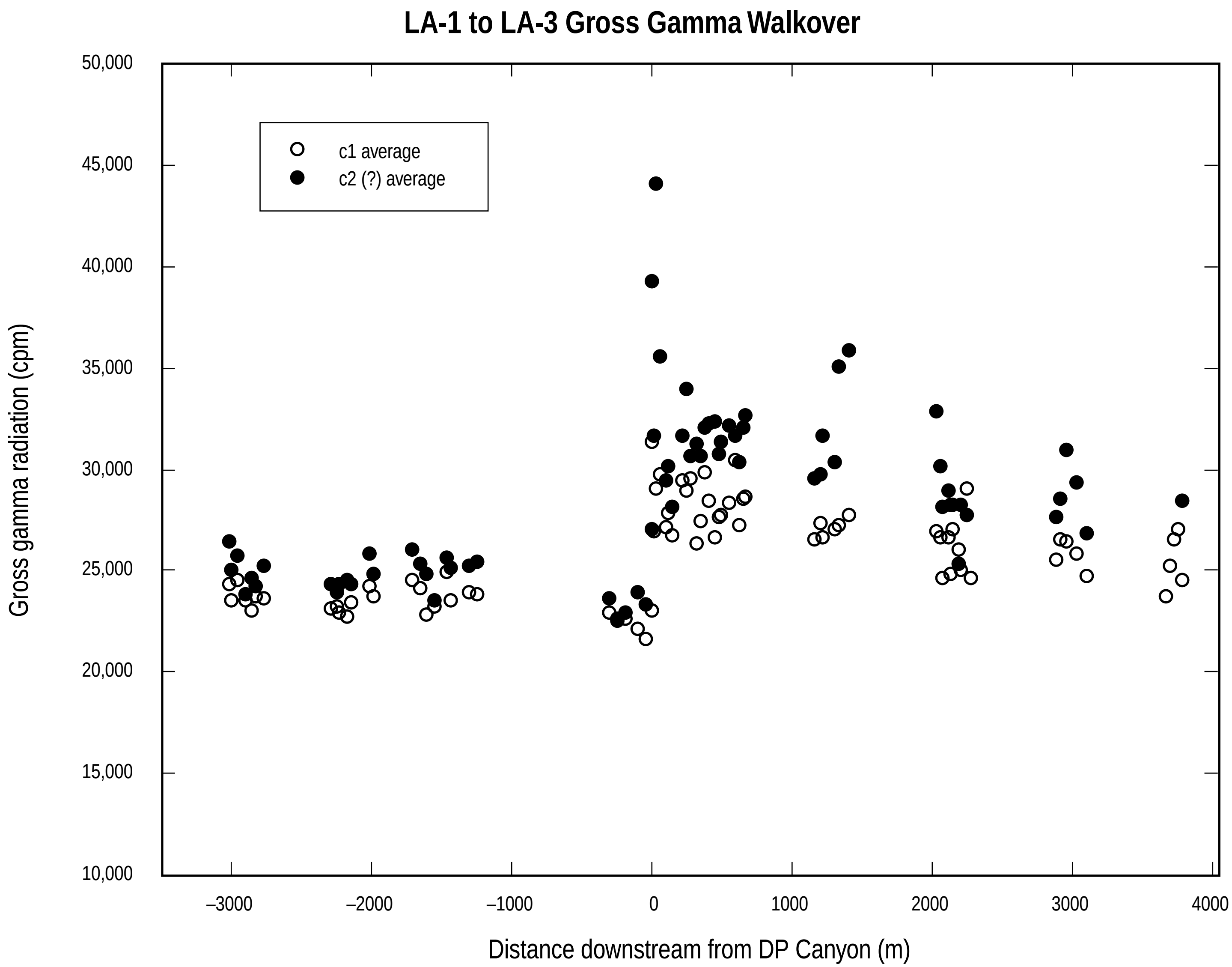

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Figure 2.3-21. Average values of gross gamma radiation measured in short walkover surveys between TA-2 and state road NM 4 plotted against distance from DP Canyon.